京都大学学術情報リポジトリ
KURENAI 紅
Kyoto University Research Information Repository

京都大学
KYOTO UNIVERSITY

Title	ECOLOGICAL STUDIES ON THE TRANSITION FROM SHIFTING CULTIVATION TO CONTINUOUS FARMING IN THE UPLAND FIELD(Dissertation_全文)
Author(s)	Hayashi, Yukihiro
Citation	Kyoto University (京都大学)
Issue Date	1993-03-23
URL	http://dx.doi.org/10.11501/3066273
Right	
Type	Thesis or Dissertation
Textversion	author

Kyoto University

2

ECOLOGICAL STUDIES ON THE TRANSITION FROM SHIFTING CULTIVATION TO CONTINUOUS FARMING IN THE UPLAND FIELD

YUKIHIRO HAYASHI

1993

Acknowledgments

This work was made possible through the kind support and cooperation of many individuals and institutions.

First of all, I am deeply indebted to my adviser, Professor of Tropical Agriculture, Kyoto University, Dr. Shoji Shigenaga, for his kind guidance, keen supervision, and untiring encouragement during the course of this work.

I would like to express my deep gratitude to Dr. Kazutake Kyuma, Professor of Soil Science, Kyoto University, for his professional guidance and helpful discussions on investigating in shifting cultivation fields, and also to Dr.Tomoo Hattori, Emeritus professor, Kyoto Prefectural University, for his guidance, valuable discussions and encouragement given me.

I am very thankful to Dr. Prateep Verapattananirund, the Laboratory of Soil Physics, Department of Agriculture in Thailand, who assisted me during all the trips for field investigation, deserves a mention and special thanks, and to Dr. Tawachai Na Nagara, head of the Laboratory of Soil Physics, Department of Agriculture in Thailand, for permitting me to use the various instruments of his laboratory that greatly helped me in obtaining the necessary data.

I wish to express my gratitude for the encouragement and support provided in various ways by Professor Kiichi Nishiyama, Associate Professor Yoshihiro Hayamichi and Lecturer Hidekazu Toyohara, Tokyo University of Agriculture, the advisor during under graduate at Tokyo University of Agriculture.

The help extended by Dr. Hideaki Hirai, the Laboratory of Soil Science, Kyoto University, and Mr. Kouji Nishio and Mr. Go Takeuti, the former students of the Laboratory of Soil Science, on a major part of soil analyses and computer operation is greatfully acknowledgement.

I wish to express my gratitude and appreciation to the following past and present staff members and students of the Laboratory of Tropical Agriculture and the Laboratory of Soil Science, Kyoto University: Dr. Naoki Utunomiya, the former Associate Professor of Laboratory of Tropical Agriculture, Dr. Eiji Nawata, Associate Professor of the Laboratory of Tropical Agriculture, Dr. Jyuichi Itani, presently Instructor of the Laboratory of comparative agriculture, Utunomiya University, and Nobuya Kobayashi, graduate student of the Laboratory of Tropical Agriculture, for their generous encouragement and guidance in the discussions on crop science; Dr. Takashi Kosaki, Associate Professor of the Laboratory of Soil Science, Dr Katutoshi Sakurai, Associate Professor of Kochi University and Mr. Ueru Tanaka, Instructor of the Laboratory of Soil Science, for their invaluable guidance in this study; Mr. Katuhiko Itami, Mr.Jyunta Yanai, Mr. Hitoshi Shinjyo, and Mr. Munehiro Ebato, graduate student of the Laboratory of Soil Science, who kindly helped me to the study site in Thailand.

Deep appreciation is due to Ms. Uta Nakaoku for the numerous miscellaneous help, and also to Ms. Haruyo Hoshino.

Scientific discussions that were conducted on many occasions with following researchers, Kyoto University contributed a great deal to this study: Dr. Hisao Furukawa, Professor in the Center for Southeast Asian Studies, Dr. Yasuo Takamura, Professor in the Center for African Area Studies, Mr. Nagao Okagawa, Lecturer of Division of Tropical Agriculture, Dr. Shigeru Araki, Associate Professor in the Center for African Area Studies.

Special thanks are given to Dr. Isamu Yamada, Associate Professor in the Center for Southeast Asia Studies, and his wife for

their great kindness in Bangkok.

My thanks are due to many of the past and present students of the Laboratory of Tropical agriculture and the Laboratory of Soil Science, Kyoto University, whose name cannot be all listed here, for providing a friendly working atmosphere.

Many thanks are due to the staff members of the Laboratory of Soil Physics, Department of Agriculture of Thailand, whose name cannot be all listed here, for their assistance and camaraderie, especially to Mr. Tamanart and Mr. Anann.

Hearty thanks are given to many villagers of Ban Rakphaendin who provided me with various support and company during the field investigation.

I am greatful to Dr.Takashi Hiraii, Director of the Environmental Engeneering and Technology Research Institute, for providing me moral support and the financial support.

Heartfelt thanks go to my mother, wife and son who constantly understand and console me when I am at crucial moments.

Many thanks are extended to Director General of the National Research Council of Thailand for permission which made me possible to carry out this reserach project in Thailand.

The expenses of this study have been in part defrayed by the Foundation for Advanced Studies on International Development.

Last but not least, thanks are also due to the Toyota Foundation, Japan, for providing me the financial support, and to Mr. Masaaki Kusumi and Gen Watanabe, Program Officer Research Grant Division of the Toyota Foundation, for their invaluable support and recommendations.

CONTENTS

List of Tables

List of figures

CHAPTER 1. Introduction

1.1 Study background

There has been a drastic decrease in forest area, particularly in the tropics. One of the major causes for this rapid decrease is the expansion of cultivated land due to the pressure of population increase and the influence of commercialism. Moreover, the increasing deforestation and reclaimed land has exerted a great influence on the global ecosystem, with such results as the greenhouse effect, due to increasing CO_2 including emission from the soil organic matter oxidation by clearing a forest. According to Houghton *et al.* in 1987, annual release of CO_2 caused by deforestation and increasing areas of shifting cultivation is estimated to be 1-2 Gt C y^{-1}.

The same situation is found in Thailand. A decrease in the total productive forest area during 1976 to 1986 was 26.1% (5176×10^3ha) of the forest area. Particularly, a sharp decrease in the same period was observed in the Northern and Northeastern region of the country. On the other hand, one estimate says in Thailand about one million people practice shifting cultivation operating on 4 million hectares of land (Dent 1992).

However, reclamation of potential arable land from the productive forest is indispensable for production of food crops. That has been evident in recent years. A problem is that reclaimed lands are utilized for cultivation only for a relatively short period of time after clearing a forest, because of a shorter fallow period, and an inappropriate provision of money, labor and technology. Thus, their capability for sustained crop production is being rapidly lost.

In general, most farmers in the tropics are not favored economically. Therefore, they cannot afford high input technology for their crop production. It is necessary to develop low input alternatives for their crop production, such as effective cropping systems, to minimize soil degradation. To assess the alternatives, it is necessary to conduct a field study on ecological changes of the transition from shifting cultivation to continuous upland farming.

1.2 Study objectives

Many studies of shifting cultivation have been carried out from anthropological or geographical viewpoints, but published studies on ecological aspects of this subject have apparently been few to date. The extensive literature on this subject in Africa was summarized by Nye and Greenland (1960), Newton (1960), and Jurion and Henry (1969), and in Latin America by Sanchez (1973). On the other hand, in Southeast Asia, close investigation on ecological aspects of shifting cultivation in Northern Thailand has been made by Nakano (1978). Another study, "Shifting cultivation, an experiment at Nam Phlom, Northeast Thailand, and its implications for upland farming in the monsoon tropics"(Kyuma *et al.* 1983), describes the results of a dynamical study on ecological aspects of traditional practice of shifting cultivation. Based on the study, the authors made the following

conclusions. 1) There are certain rationales in the traditional system of shifting cultivation which are able to continue crop production for food, providing fallow periods following short periods of cultivation could be long enough for completing secondary forest regrowth. 2) Some merits in the practice of traditional shifting cultivation drawn from the study may help the establishment of stable upland farming, for example adoption of zero- or minimum-tillage, mulching and intercropping systems.

However, the actual situation of shifting cultivation in Northern Thailand is more serious than expected. During the dry season of 1990, the author traveled in Northern Thailand to investigate the shifting cultivation area. In most slash and burn fields, long-cultivation and short-fallow was observed to be the norm. Moreover, tractor tillage has been carried out in these fields, despite steep sloping land. Most fields were used to cultivate some cash crops, such as maize, ginger and garlic, under no fertilization and single-cropping conditions. Thus, the present practices may be regarded as semi-continuous upland farming with slash and burn practice without compensation of the soil degradation. If farmers continue such a practice for a few decades, the forest in the area not only disappears, but also even the area of arable land may decrease seriously.

The objectives of this study, therefore, were to elucidate the ecological changes during the transition from the initial state just after clearing a forest to a long-term cultivation state with slash and burn practices, and the ecological advantages of multiple cropping systems, by on-farm research. Furthermore, the author hopes that results obtained from this study will contribute to the development of sustainable agriculture in the monsoon tropics.

CHAPTER 2. Description of study area and research procedure

2.1. Location and climate

The study area is located in the northernmost part of Thailand at the latitude of 19°50'N and the longitude of 100°23'E with an approximate elevation of 500 m above the mean sea level. Administratively, it is included in Ban (village) Rakphaendin, Tambon Tab Tao, Amphoe (district) Thoeng, Changwat (province) Chiang Rai as shown in Fig.2-1.

Based on Kyuma's classification of climate in South-East Asia (1977) and Koeppen's, the study area is classified as Group VII, in the Central India-Northern Indochina Region, or Koeppen's Aw. According to the climatic data obtained from the study site between April 1991 and March 1992 (Table 2.1), and between April and September 1992 (Table 2.2) and from the Chiang Rai Horticulture Research Center near Chiang Rai city between 1982 and 1992 (Table 2.3), in the dry season, the monthly minimum temperature during the period from December through February is usually below 13°C, and in the rainy season, it went up to above 20°C during the period from April through October at Chiang Rai and from April through September at the study site in 1991, though below 19°C in April, August and September in 1992. The monthly maximum temperature exceeds 30°C from February through September at Chiang Rai, and from March through July at the study site.

Annual rainfall ranged from 1,324mm to 1,936mm. Mean monthly rainfall was fluctuating from zero in March to 640mm in August. The fluctuation was quite large. The daily maximum rainfall was 155mm in the study area in 1991, but only 62mm in 1992. A shortage of rainfall limited crop growth during the dry season, whereas it was considered as enough for growing annual crops during the rainy season in 1991. However, in the rainy season of 1992, sum of rainfall from April through September was less than a half of rainfall of 1991, in comparison with the same period. Thus, farmers in the study site could not but delay the planting time because of a shortage of rainfall on April and May in 1992. Moreover, through the all cropping period, monthly rainfall in 1992 was much less than that in 1991. Therefore, these facts should be taken into consideration when crop productivity between in 1991 and 1992 is compared.

Sunshine data was recorded from April through November in 1991. The monthly sum of daily sunshine was above 10,000cal/cm-2/month in April and May, and September. The monthly maximum sunshine was highest in May, attaining above 13,000cal/cm-2/month. The result was that there was a peak of sunshine between April and May, following September and October. The Monthly minimum sunshine was between June and August due to have much heavier rainfall or many cloudy days. However, even the month of minimum sunshine, the data was above 9,000cal/cm-2/month. Thus, it can be considered that there is no limiting factor of crop growth for sunshine in the study area.

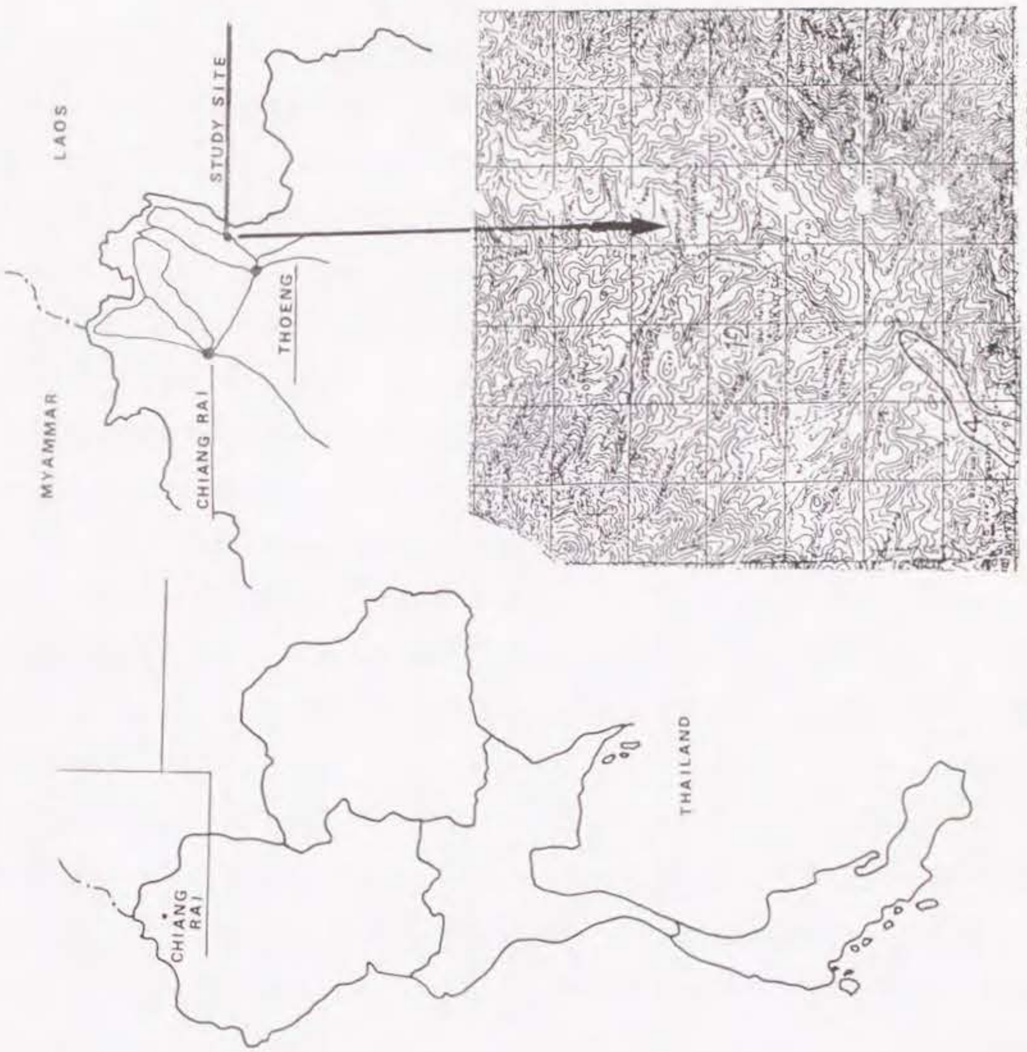


Fig.2-1 Map showing the location of study area

Table 2.1 Mean monthly temperature and rainfall from April in 1991 to March in 1992 at Rakphaendin village

	1991 Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	1992 Jan.	Feb.	Mar.	year
Temperature(°C)													
Mean	26.9	28.6	26.9	27.8	27.8	24.3	23.2	20.2	18.0	16.1	18.8	24.2	23.6
Maximum	36.1	34.7	30.5	31.8	29.3	29.2	28.8	26.6	25.5	24.3	28.9	33.7	29.9
Minimum	21.6	22.5	23.3	23.7	22.1	19.5	17.6	13.9	10.5	7.9	8.6	14.7	17.2
Rainfall(mm)	73	295	195	213	640	225	52	34	17	2	5	0	1751
Days of rainfall	6	14	17	12	26	22	15	5	2	1	3	0	123

Table 2.2 Mean monthly temperature and rainfall from April to September in 1992 at Rakphaendin village

	1992 Apr.	May	Jun.	Jul.	Aug.	Sep.
Temperature(°C)						
Mean	27.6	26.7	25.3	23.3	22.3	23.2
Maximum	36.5	33.8	30.4	27.3	27.2	27.6
Minimum	18.7	19.6	20.2	19.2	18.5	18.8
Rainfall(mm)	40	94	47	171	185	173
Days of rainfall	4	9	9	20	21	19

Table 2.3 Annual temperature and rainfall from 1982 to 1991 at Chiang Rai

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Temperature(°C)										
Mean	24.4	24.6	24.7	24.6	24.4	24.8	24.7	24.9	25.0	25.1
Maximum	30.3	30.8	30.6	30.4	30.4	30.7	30.7	31.0	30.8	31.1
Minimum	18.5	18.5	18.8	18.8	18.4	18.9	18.7	18.7	19.2	19.0
Rainfall(mm)	1351.5	1929.6	1512.9	1914.3	1416.8	1426.4	1660.2	1501.7	1683.8	1633.2
Days of rainfall	131	137	140	140	134	125	150	142	134	143

Cited from Chiang Rai Horticulture Research Center, Climatological Data, 1992.

2.2.Village life

2.2.1 Development of the village

Ban Rakphaendin was formerly called Ban Huai Tin Tok which comprised some 30 families of Yao (Iu Mien) people practicing shifting cultivation. In 1967 the Yao people migrated to other places due to the danger from nearby battle fields between the Thai soldiers and the Communist Guerrillas. After the unrest was ended in 1980, the Thai Army planed a resettlement program in the area for the national security purposes. In 1981 a reservoir was constructed for household use and as the power source of a 50 KW electric generator which has been operated since 1983.

In 1981 the Thai Army also started to recruit people from among those, living in the neighboring lowland areas, and possessing no lands to cultivate. The qualified persons would received use-rights of about 15 rai (1ha=6.25rai) of mostly sloping land.

When the village was established in 1982, it comprised 49 households of Thai people. Since then some of them have moved out to the lowlands again due mainly to the difficulties in living in this mountainous area. In 1987 the number of Thai households decreased to 28 and, instead, 10 households of Hmong people were allowed to live in the village. At present there are 50 households with 286 inhabitants. Fifty-four percent of the total population are younger than 20 years old whereas only six percent are older than sixty. While the Thai people tend to move out to find a better life in lowland areas, Hmong people are moving into the village because of better communication and facilities. As a result Hmong people are now the majority with 34 households and 220 inhabitants. The movement of villager and population are shown in Fig.2-2 and Fig.2-3, respectively.

2.2.2 Land tenure and land-use

An important objective of the resettlement program was to maintain the national security by developing the sense of belonging and loyalty to the nation. Since all land in the area was regarded as public domain, property of the State. A portion of the uplands around the village was divined into 50 units having an area about of 15 rai each. Use-rights of the land, one unit per household, was given to the villagers but document of land title was not issued. Thus they can be only possessors not owner resulted in that they cannot legally sell the land to other persons. The right of possession will remain as long as the person lives in the village, in other words, it ceases if the possessor leaves the village permanently for new place.

All families in the village are directly involved in agriculture. Only few of them supplement their incomes with wage labor. In practice the villagers cannot make their living only on the land officially provided because they can continuously cultivated the land for a period of 2-4 years due primarily to weed problems, in particular *Imperata* spp., which occur after clearing the forest. In the first year after clearing they usually grow

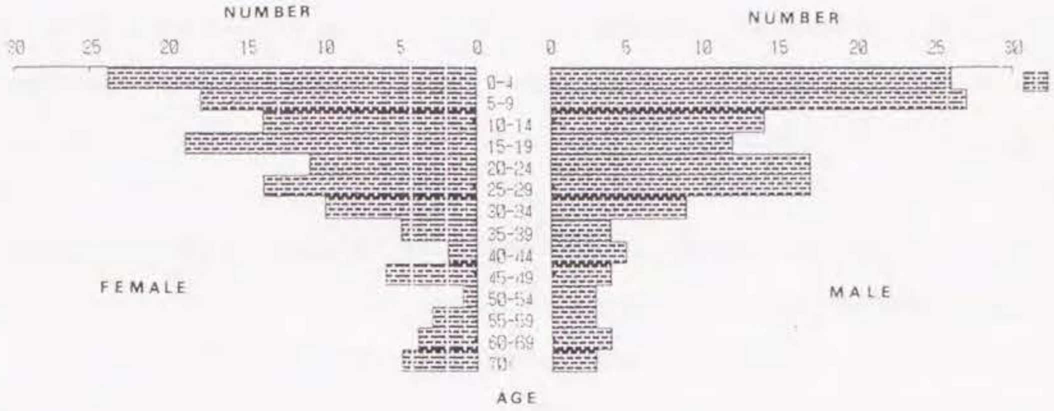


Fig.2-3 The number of villager in different age

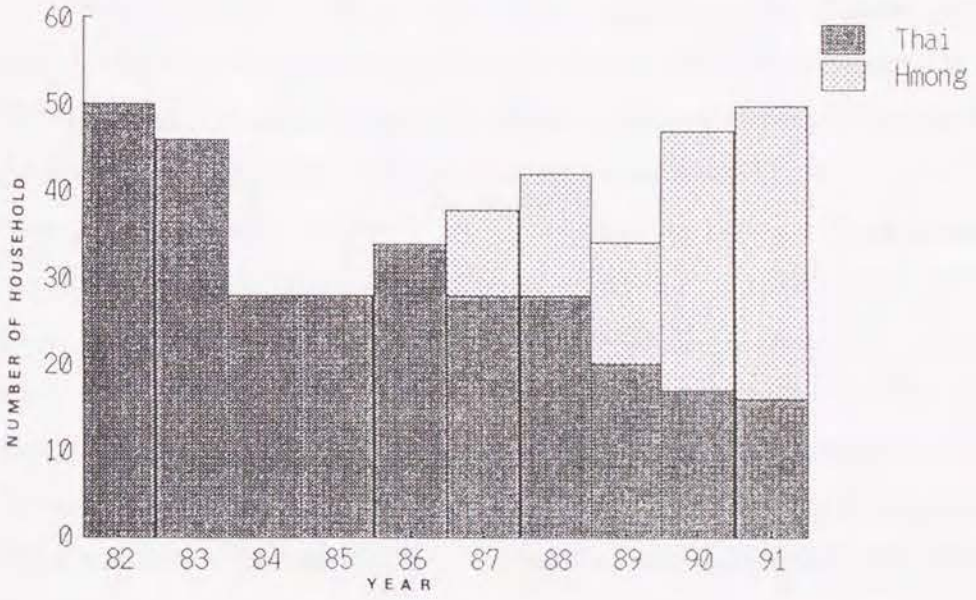


Fig.2-2 Dynamics of village population

upland rice for subsistence and maize as a cash crop from the second year. Then the land must be kept fallow for a period of 4-5 years, not as long as other cases reported in several literatures. Thus a minimum of 4-5 land units per household is needed for rotation in their process of shifting cultivation. As a result, vast forest areas with convenient access were illegally brought under shifting cultivation.

In the past unoccupied land plentiful, the suitable land for agriculture could be easily acquired. The person who permanently left the village did not have an idea of selling his occupied land. His use-right of the land was given freely to the new person adopted into the village by the village committee. As the population continues to grow resulted in increased demand of land. In recent years the villager who planed to move out sold his house including the use-rights of the household and land officially provided and the occupied land before leaving the village. Although this practice is illegal, it is recognized by the villagers.

2.3 Research procedures

An ecological study was started in 1990 in slash and burn fields with different land-use history under the same climate, soils and farming practice. The study site was farmer's fields cropped maize without fertilization.

In the first year of this study (1990) these fields were divided into three parts according to the land-use history, and an investigation of soils, weed and crop has been carried out under maize cropping for three years in each field. In the second year(1991) the experimental field was set up within the study area by clearing and burning a secondary forest after the present practice of the villager, and studies to characterize the initial state of the slash and burn field and to evaluate the effect of tillage by tractor on maize cropping were conducted. In the third year (1992) another experimental field was cleared, and studies to evaluate the effect of the various cropping practice on the yield, the biomass and root system of maize, upland rice and soybean were conducted.

Thus, in this paper the experimental fields were divided into five, i.e. F2, F3, F4, F5 and F6. These fields are characterized by different land-use histories, that is, the successive cropping periods of F2, F3, F4 and F5 were 4, 5, 10 (with two 1 year fallows) and 1 year, respectively, and F6 just after clearing as in 1992, as shown in Table2.1. In the case of F4, F5 and F6, these fields were divided to two parts by whether tillage was conducted or not. A no tillage plot along the T51 and T61 line and a tractor tillage plot along the T4, T52 and T62 line were compared in order to make clear the effects of tractor tillage on crop production and soils which has been rapidly wide spreading in Thailand recently.

In all fields, observations and measurements of various ecological factors were carried out under single-cropping of maize, and among them two fields were used due to conduct some experiments with respect to various cropping practice.

Table 2.4 Land-use history in each field

Field	Year of clearance	land use
F-2	1988	maize with no-tillage
F-3	1987	maize with no-tillage
F-4	1981	maize with no-tillage and two times of 1 year fallow, and with tractor tillage since 1990
F-5NT	1991	maize with no-tillage after 8 year fallows
F-5TT	1991	maize with Tractor tillage after 8 year fallows
F-6NT	1992	maize, upland rice and soybean with no-tillage under single-cropping and intercropping conditions
F-6TT	1992	maize, upland rice and soybean with tractor tillage under single-cropping and intercropping conditions
F-6NBNT	1992	maize with no-tillage and no-burning under single-cropping conditions

2.4 Appraisal of the research procedures

i) Site selection and characterization

Site selection on the research of shifting cultivation is an important factor in order to represent actual situations. The study site in this research was selected after field survey which involved interview with farmers about the history of land-use, present farming practices, crop yield and natural vegetation. Soil survey was also performed in some locations. The field trips covering 7,000 Km were made in the North and West Continental Highlands of Thailand in 1990.

The study site in Chiang Rai province is included in the monsoon tropics, and located about 40 Km east of Chiang Rai city. The climate conditions of the study site have not been very different from that of Chiang Rai city in the past decade. According to the geology map made by the Mineral Resources Department of Thailand, geography and geomorphology in the study area are full developed mountains with belonging to "Tanaosi group", which consists of sedimentary rocks of the Paleozoic era. The soils covering the mountains may be classified as " Reddish Brown Lateritic Soil". The vegetation cover in the study area, based on the climatic conditions, can be regarded as "Mixed Deciduous Forest", which has been broadly replaced by secondary forest due mainly to shifting cultivation.

The investigation was carried out on steep sloping lands ranged from 12° to 36°. Nearly, everywhere in Southeast Asia, shifting cultivation is practiced on such steep slopes. An elevation of the study site was about 500 m above the mean sea level, although shifting cultivation is practiced in the higher altitude sites, too.

Most of villages in the study area were established by immigration of lowland farmers according to a resettlement program planed by the Thai Army. However, Hmong people, who are shifting cultivator moved from Yunnan in China through Laos, are now the majority in broad area. Their farming in slash and burn fields include long-cultivation and short-fallow, or long-cultivation and abandonment. With respect to the period of cultivation and fallow, these practices are clearly different from traditional shifting cultivation. Moreover, in a past few years, even a tillage with tractor has been introduced into their slash and burn field on the sloping land. Therefore, this study was carried out at the fields where lowland farmer or Homng people practice a slash and burn agriculture. Such a practice has been commonly done in northern Thailand, in a past few decades. Hence, the study site selected for this research may be estimated to reflect the present situation of shifting cultivation in the monsoon tropics.

ii) Research procedures

At first, ecological studies were carried out on farmers field with different land-use histories under the same practices and crops. The second, the effect of intercropping systems in the slash and burn fields on crop ecology was investigated, in special reference with morphological changes of the root

distribution of the crops under single-cropping conditions as well.

The farmers practices of the study site can be described as follows: in the dry season before premonsoon showers, woody vegetation in fallow and crop residues and weeds in successive cropping are cut, and then burnt. A field is fired at random direction, although traditional shifting cultivation is burnt from the top to downward due to keep burning for longer time, so called "good burn". In most of their fields, only very shallow cultivation with hoe is practiced. Some farmers have plowed using tractor with disk upto 30-40 cm depth. Maize seeds are sown into the hole dug with hoe when rain lasts several days in the end of April or to May. The crops are harvested in August or September according to the sowing time. Multiple cropping systems and mulching are not generally practiced in the study area, in contrast with traditional shifting cultivation. This should be kept in mind when an establishment of continuous upland farming is developed in this area.

An investigation was conducted at field after farmers practices. The investigation revealed changes on the soil fertility and the crop production of the fields having different land-use histories, in 1991 and 1992. However, the crop production obtained in 1992 was considerably different from that in 1991 because of scarcity of rainfall compared with average rainfall in the past decade in Chiang Rai province. Therefore, it may be necessary to continue the field investigation in time series for the further research.

The experiment on different cropping systems was carried out at the field just after clearing the secondary forest. Crop combinations, which are commonly practiced in the tropics, were used in this experiment. An experiment with a combination of maize and soybean had been carried out in experimental field in Japan, before conducting similar experiment in Thailand. Hence, an experiment on cropping systems could be compared between field research in an experimental farm in the temperate region and on-farm research in slash and burn field in the monsoon tropics.

CHAPTER 3. Topography and soils in study site

3.1 Topography

3.1.1 Methods

A topographic map of the study site was prepared, making by a clinometer, a bamboo stick, and a tape measure (Fig.3-1), before dividing the study site. The elevation of the study site was measured by an altimeter. As shown in Fig.3-1 , a circle mark is a standard point for the investigation of the topography, a star mark is a point where a soil profile was described and soil was sampled, and a square mark is a point where an equipment for the evaluation of the amount of run-off is settled.

Soil depth distribution along of T2, T3, T4, T51, T52, T61 and T62 was investigated in order to distinguish soils from bed rock. A boundary of bed rock was defined as a layer with more than 50 percent of rocks.

3.1.2 Results and discussion

As shown in Fig.3-1, the experimental fields for the study were located on both sides of a small valley, and consist in two hilly fields on the north and three fields on the gentle hillside on the east. The slope gradient of the experimental fields ranged from 12° to 36°, and the slope of F2 and F3 is steeper than that of F4, F5 and F6. Elevation at the bottom of valley is about 500m above mean sea level. In rainy season, a spring is

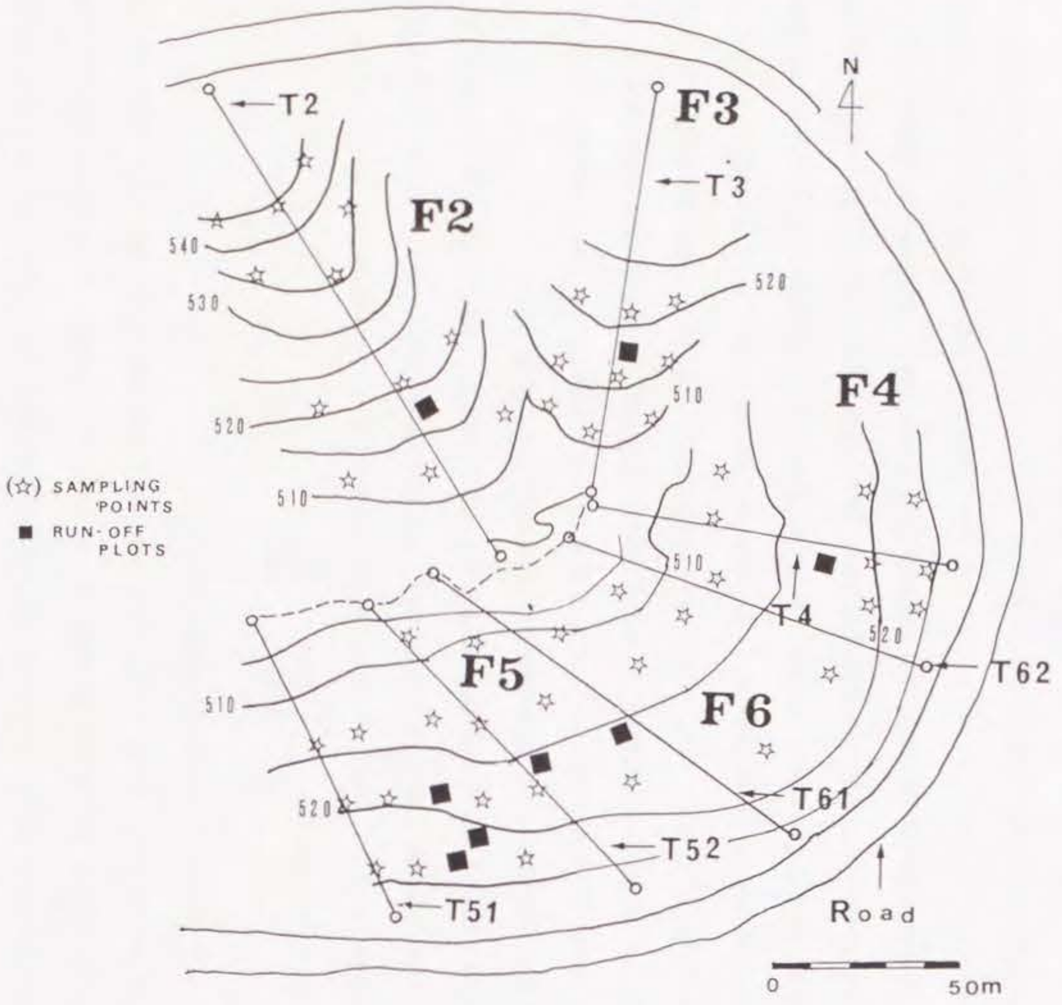


Fig.3-1 A topographical map of the study site

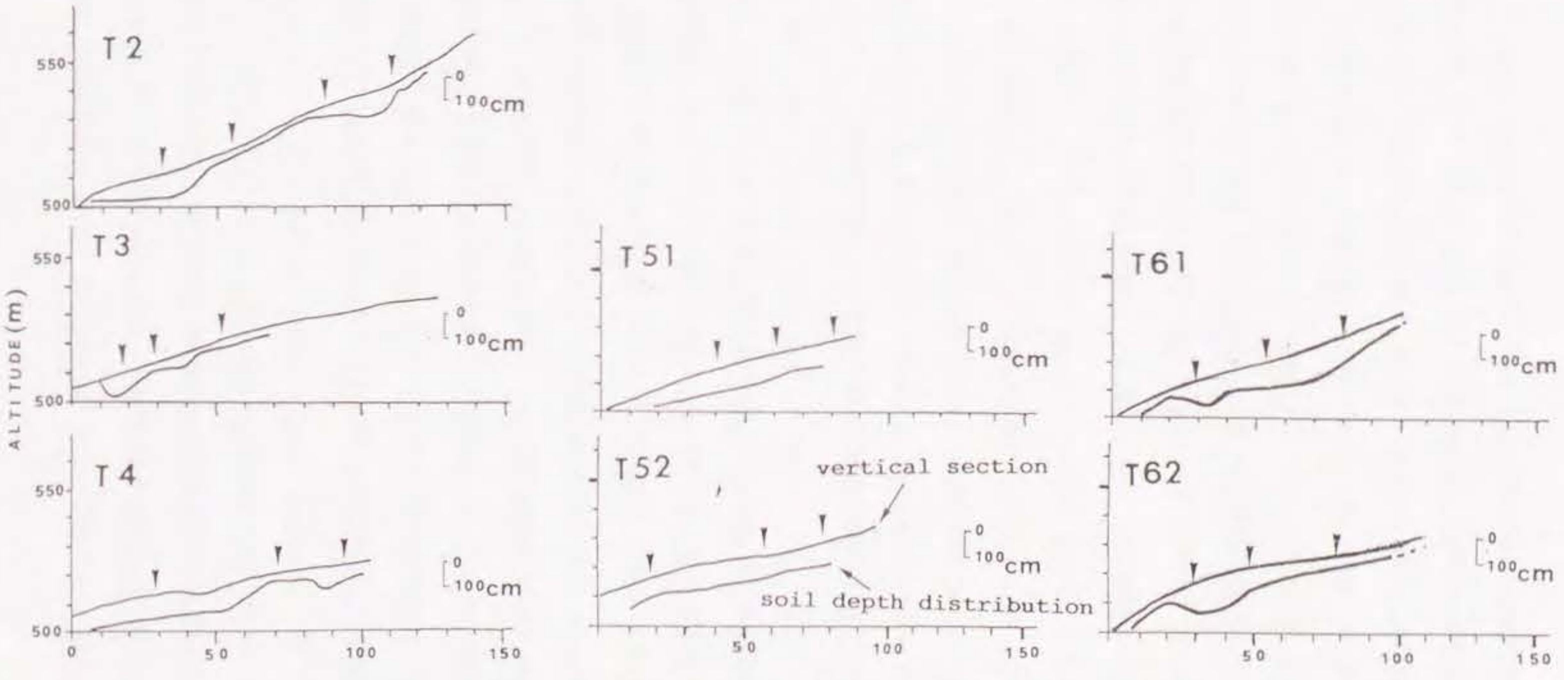


Fig.3-2 Vertical section and soil depth distribution along the T-line in Fig.3-1

▼: arrows show sampling points in field

flowing out in a westward direction, and join Ngao river.

Soil depth in each transect is shown in Fig.3-2a and Fig.3-2b. Based on these figures, the soil depth tended to be thicker in the lower part of a slope. In the case of T4 in F4, the soil depth was relatively deep except in the middle part, whereas in the case of T51 in F5 and T52 in F5, the soil depth was deep in all parts. After these investigations, a sampling points, which were shown by a wedge mark in the Fig.3-1 was determined.

3.2 Soils

3.2.1 Soil samples examined and analytical methods

For the determination of gravel contents, soils at 0 to 10 cm, 10 to 20 cm, and 20 to 30 cm were sampled. For the chemical characteristics of the fine earth fraction (less than 0.2 cm), soils at 0 to 10 cm, 10 to 20 cm, and 20 to 30 cm were sampled and soils below 30 cm were sampled at every soil horizon. For the examination of changes in soil characteristics before and after burning composite soil samples at 0 to 5 cm and 5 to 10 cm were made by mixing the soil samples collected from 8 points around the soil sampling points.

Disturbed soil samples at 0-10, 10-20, 20-30 cm depth were collected to determined fertility status and undisturbed 100 cc core sample for physical properties. The figures of chemical properties were calibrated on the basis of total weight of the

soil mass (fine earth + gravel). A principle component analysis with varimax rotation was employed on data analysis.

Moist soils sampled for chemical analyses were air-dried, crushed, and sieved through 2 mm sieve, and then the water content were determined.

Soil chemical and physical characteristics were determined by following methods.

(1) pH (H2O,N-KCl)was determined by a glass electrode pH meter with a soil to solution ratio of 1 to 5. (2) Exchangeable bases were extracted by NH4OAC, and the Ca and Mg were determined by atomic absorption spectrometry and the Na and K by flame emission spectrometry. (3) Exchangeable acidity was determined by titration of 0.01N HCl and successively exchangeable Al by titration of NaOH after addition of 1M NaF. (4) Available Phosphorus was determined by molybdenum blue method after extraction by Bray No.2 solution. (5) Total carbon and nitrogen were determined by CN-corder.

(6) Air phase volume was determined by volumenometer and water phase and bulk density by oven drying at 105°C. (7) Saturated hydraulic conductivity by permeameter at constant head. (8) Moisture characteristics by sand column, pressure plate and centrifugation at 0 to 3.16 KPa, 3.16 to 100 KPa, 1500KPa, respectively. (9) Soil texture was determined by the pipette method. The < 2mm soil fraction was treated with H_2O_2 and dispersed 1 N NaOH. Sand fraction were separated by wet sieving, and silt and clay fraction by sedimentation. The particle-size classes are coarse sand, 2-0.2; fine sand, 0.2-0.02; silt, 0.02-0.002; and

clay, < 0.002 mm. The textural classification was made according to the system adopted by the Japanese Society of Soil Science and Plant Nutrition.

3.2.2 Results and discussion

i) Relationships between gravel contents in soil and topography

Gravel contents at 0-10, 10-20, and 20-30 cm depth and the value of the slope gradient are given in Table 3.1. Average values of gravel contents at 0 to 30 cm are summarized in Table 3.2. Based on the weight percentage of the fine earth fraction (Table 3.2), soils examined may be divided into the following three Groups;

Group 1: Fine earth fraction is more than 90%
Group 2: Fine earth fraction is in between 70% and 90%
Group 3: Fine earth fraction is less than 70%

Soils assigned to Group 1 and T21, T31, T41, T511, T512, T513, T521, and T523. Soils assigned to Group 2 are T23, T42, and T522. Soils assigned to Group 3 are T22, T24, T32, and T33.

Fig.3-3 shows a significant correlation between slope gradient and the weight percentage of the fine earth fraction. This suggests that 1) weight percentage of the fine earth fraction decreases with increasing slope gradient, 2) if the slope gradient is larger than 20°, the fine earth fraction is less than 60%, and 3) if the slope gradient is smaller than 12°,

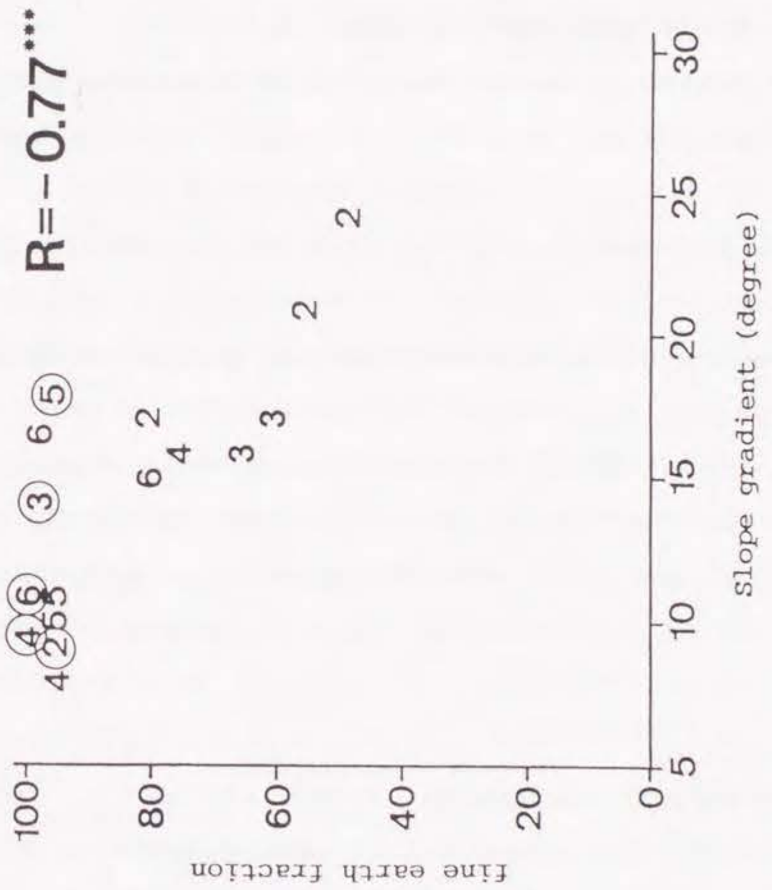


Fig. 3-3 Scattergram of fine earth fraction and slope gradient.
2: T2, 3: T3, 4: T4, 5: T52, 6: T51
○: the lower part of each slope

the weight percentage of the fine earth fraction is more than 90%.

Thus, topographic characteristics of three Groups are summarized as follows:

1) Group 1 is characterized by the slope gradient smaller than 12° or located in the lower part of slope.

2) Group 2 is characterized by the value of the slope gradient in between 12° and 20° and located in the middle or upper part of slope.

3) Group 3 is characterized by the value of the slope gradient larger than 20°.

Table 3.3 shows the correlation data between gravel contents and the value of the slope gradient, indicating that very large gravel or fine earth fraction is correlated with the slope gradient most significantly. Hence, it is concluded that as the value of the slope gradient increases, the weight percentage of the fine earth fraction decreases and very large gravel content increases.

ii) Soil fertility in each field

The data in Table 3.4 are modified with respect to gravel contents to evaluate fertility of field soil but not of fine earth fraction. Based on Table 3.4, the following statements may be made.

1) Soil pH tended to decrease with depth. The soil pH of F5 was lower than that of F2,F3 and F4. Exchangeable Al increased with depth in F5. These suggest that soils that have been fallowed for

eight years are subjected to acidification, resulting in higher amount of Ex.Al in the subsoil, whereas soils under successive cropping are subjected to neutralization caused by ash addition (Table 3.5).

2) Exchangeable Ca, Mg, total carbon, total nitrogen, and available phosphorous in F2, F3 and F5 decreased with depth, whereas those in F4 fluctuated within the profile, indicating a mixing by tractor tillage.

3) The higher the gravel contents, the lower the Ex.Ca, Ex.Mg, total carbon, total nitrogen, clay content, and available phosphorous, suggesting that gravel contents greatly affect soil chemical properties and hence soil fertility.

4) Hydraulic conductivity was highest in F4 and moisture content at 100kPa was lower in F4 than in F2, F3 and F5, since tractor tillage promotes permeability and reduces water holding capacity.

Kosaki et al. (1989a) employed a principal component analysis to extract factors causing soil variation in soil pH, organic carbon, available phosphorous, exchangeable cations and particle size distribution, and extracted four factors to be named as 1) inherent fertility factor, 2) available phosphorus factor, 3)acidity factor, and 4) organic matter factor. Moreover, Kosaki et al. (1989b) identified yield determining factors by a principal component analysis in rice growing environment, and performed a regression analysis to derive a yield prediction function using the extracted factors.

The author also performed a principal component analysis with varimax rotation to extract factors causing soil variation in soil pH, organic carbon and nitrogen, exchangeable cations (Ca,Mg,Al) and clay content, hydraulic conductivity and moisture content at a suction of 100kPa. Three factors were extracted as shown in Table 3.6 and Table 3.7. Based on the correlation in Table , Factor 1 is positively correlated with exchangeable Ca and Mg, and total carbon and nitrogen, so that it is considered soil chemical fertility factor. Its high positive score implies a high soil chemical fertility. Factor 2 is positively correlated with exchangeable Al and clay content, and negatively correlated with pH(H20), and hence it is considered to be an acidity factor. Its high positive score implies a high acidity. Factor 3 is negatively correlated with moisture content at 100kPa tension and positively correlated with hydraulic conductivity. It is thus interpreted as a dryness factor. Its high positive score implies a tendency to be readily dried.

Based on these factor scores shown in Table 3.8, the following statement may be made.

1) Soil chemical fertility decreases with depth in F2, F3 and F5, while it fluctuates in F4, indicating an effect of tractor tillage. In F2 and F3, the factor score is governed by a location on a slope, that is, the score is lower in steep sloping locations with a high gravel content (Table 3.2). On the other hand, a low soil chemical fertility in a deeper horizon of F5 is attributable to low exchangeable Ca and Mg contents, which are resulted from leaching during the fallowed period.

2) Acidity factor is much higher in F5 than F2, F3 and F4, suggesting that acidity developed under the leaching condition of

Table3.1 Gravel size distribution and slope gradinet.

Field[1]	Location[2]	Depth (cm)	V.large[3] gravel (%)	Large[3] gravel (%)	Medium[3] gravel (%)	Small[3] gravel (%)	Fine[3] earth (%)	Slope gradient (degree)
2	1	0-10	0.00	0.48	1.32	2.20	96.00	9
		10-20	0.00	0.61	2.05	2.66	94.66	
		20-30	0.17	0.70	2.45	2.69	93.96	
	2	0-10	15.63	9.74	7.48	3.28	63.85	21
		10-20	25.69	7.93	7.01	5.08	54.29	
		20-30	32.04	8.43	6.78	3.63	49.11	
	3	0-10	0.71	1.36	4.78	4.67	88.46	17
		10-20	0.85	2.05	4.58	3.81	88.71	
		20-30	7.92	6.24	12.00	7.74	66.09	
	4	0-10	18.26	8.15	9.90	6.74	56.93	24
		10-20	45.92	5.71	6.82	4.57	36.95	
		20-30	32.77	7.28	7.86	4.76	47.32	
3	1	0-10	0.00	0.13	0.20	0.94	98.72	14
		10-20	0.03	0.06	0.23	0.57	99.10	
		20-30	0.00	0.40	0.74	1.25	97.60	
	2	0-10	13.29	5.88	7.34	5.27	68.22	17
		10-20	29.21	7.79	8.81	5.60	48.58	
		20-30	16.47	6.10	9.44	8.24	59.73	
	3	0-10	2.66	6.86	9.95	6.42	74.10	16
		10-20	5.61	9.63	15.04	8.37	61.33	
		20-30	9.41	8.48	15.58	9.09	57.43	
4	1	0-10	0.15	0.06	0.03	0.26	99.49	9.5
		10-20	0.00	0.05	0.05	0.30	99.59	
		20-30	0.07	0.09	0.09	0.28	99.46	
	2	0-10	4.18	4.08	5.32	5.00	81.41	16
		10-20	4.34	3.17	4.77	4.01	83.70	
		20-30	17.53	9.44	9.19	5.62	58.20	
	3	0-10	0.27	0.53	1.71	2.42	95.06	8
		10-20	0.38	1.17	2.58	3.13	92.73	
		20-30	0.31	0.65	0.76	1.09	97.18	
5	1	0-10	0.40	0.39	1.19	1.36	96.64	18
		10-20	0.58	1.28	1.94	1.85	94.35	
		20-30	0.29	0.47	1.33	1.80	96.10	
	2	0-10	0.52	0.53	1.07	1.68	96.19	11
		10-20	0.22	0.75	1.34	1.94	95.74	
		20-30	1.01	1.50	2.09	2.17	93.22	
	3	0-10	0.00	0.12	0.68	2.18	97.01	10
		10-20	0.17	0.51	1.39	2.62	95.30	
		20-30	0.51	1.02	1.14	2.06	95.25	
6	1	0-10	0.05	0.22	0.45	0.92	98.34	11
		10-20	0.00	0.46	0.82	1.00	97.71	
		20-30	0.52	0.24	0.52	0.86	97.84	
	2	0-10	3.74	3.29	4.75	3.17	85.04	15
		10-20	9.75	4.90	7.89	4.33	73.11	
		20-30	4.77	4.41	5.99	3.56	81.26	
	3	0-10	0.00	0.19	0.42	0.84	98.55	16.5
		10-20	0.05	0.32	0.63	1.03	97.96	
		20-30	0.08	0.12	0.32	0.71	98.76	

1) 2. 3rd year, 3. 4th year, 4. 9th year, 5 and 6. 1st year
2) 1. lower slope, 2. middle slope, 3. upper slope
3) V.large gravel: larger than 2cm, Large gravel: 1 to 2cm, Medium gravel: 0.4 to 1cm, Small gravel: 0.2 to 0.4cm, Fine earth: smaller than 0.2cm

Table 3.2 Gravel size distributin and slope gradient in each samping point.

Tran-sect	Samling points	V.large[1] gravel (%)	Large[1] gravel (%)	Medium[1] gravel (%)	Small[1] gravel (%)	Fine[1] earth (%)	Slope gradient (degree)
T2	1	0.06	0.60	1.94	2.52	94.88	9
	2	24.46	8.70	7.09	4.00	55.75	21
	3	3.16	3.22	7.12	5.41	81.09	17
	4	32.32	7.05	8.20	5.36	47.07	24
T3	1	0.01	0.20	0.39	0.92	98.47	14
	2	19.66	6.59	8.53	6.37	58.84	17
	3	5.89	8.33	13.53	7.96	64.29	16
T4	1	0.08	0.07	0.06	0.28	99.52	9.5
	2	8.68	5.57	6.43	4.88	74.44	16
	3	0.32	0.79	1.68	2.21	94.99	8
T51	1	0.43	0.71	1.49	1.67	95.70	18
	2	0.59	0.93	1.50	1.93	95.05	11
	3	0.23	0.55	1.07	2.29	95.86	10
T52	1	0.19	0.31	0.60	0.93	97.96	11
	2	6.09	4.20	6.21	3.69	79.80	15
	3	0.05	0.21	0.46	0.86	98.42	16.5

1) V.large gravel: larger than 2cm, Large gravel: 1 to 2cm, Medium gravel: 0.4 to 1cm, Small gravel: 0.2 to 0.4cm, Fine earth: smaller than 0.2cm

Table 3.3 Correlation between gravel contents and slope gradient.

	V.large gravel	Large gravel	Medium gravel	Small gravel	Fine earth
Slope gradient (degree)	0.78^{***}	0.71^{**}	0.60^{*}	0.53^{*}	-0.77^{***}

***: significant at 0.1%, **: significant at 1%
*: significant at 5%

Table 3.4 Soil physical and chemical properties modified by gravel contents.

Field[1]	Loc.[2]	Lay.[3]	pH H_2O	pH KCl	K	Ca	Mg	Al	P_2O_5 (mg/100g)	Total C (%)	Total N (%)	HC[4] (mm/hr)	Moisture[5] (%)	clay (%)	Gravel (%)
					Exchangeable cations -----	(cmol(+)/kg)	----								
2	1	1	6.57	5.62	0.91	6.05	2.22	0.00	5.27	2.66	0.22	295	26.8	44.74	4.00
		2	6.51	5.23	0.53	3.81	1.34	0.00	1.84	1.61	0.15	77	32.3	49.51	5.32
		3	6.29	4.82	0.29	2.39	1.14	0.00	1.08	1.19	0.12	61	32.7	52.24	6.01
	2	1	6.30	5.22	0.45	2.67	1.55	0.00	4.69	1.76	0.14	232	27.6	30.20	36.13
		2	6.12	4.77	0.33	1.43	0.88	0.00	2.25	0.94	0.10	185	24.3	26.22	45.71
		3	6.23	4.89	0.34	1.48	0.84	0.00	1.46	0.63	0.10	.	.	24.41	50.88
	3	1	6.36	5.38	0.87	4.61	2.33	0.00	5.23	2.41	0.19	95	30.4	39.36	11.52
		2	6.30	4.67	0.28	1.50	1.91	0.00	1.21	1.11	0.17	42	30.8	42.05	11.29
		3	6.01	4.47	0.16	0.81	1.31	0.19	0.69	0.70	0.07	11	32.7	31.33	33.90
	4	1	6.61	5.96	0.41	2.90	2.12	0.00	5.07	1.39	0.11	61	25.9	20.55	43.05
		2	6.65	5.69	0.18	1.17	1.00	0.00	1.70	0.51	0.05	100	24.2	13.04	63.02
		3	6.57	5.47	0.20	0.94	1.13	0.00	0.97	0.41	0.04	370	32.2	17.37	52.67
3	1	1	6.10	4.91	0.37	4.31	1.68	0.52	4.10	2.34	0.23	285	30.9	47.68	1.27
		2	5.34	4.30	0.17	2.94	1.00	0.00	1.19	1.69	0.19	77	31.4	44.30	0.89
		3	5.77	4.46	0.16	3.18	1.03	0.21	1.30	1.32	0.14	22	33.9	50.17	2.39
	2	1	6.56	6.13	0.74	7.74	2.04	0.00	15.57	2.55	0.23	232	27.7	31.72	31.78
		2	6.38	5.62	0.36	3.43	0.72	0.00	2.97	1.16	0.12	68	30.7	22.15	51.41
		3	6.14	5.12	0.26	2.93	0.48	0.00	1.17	0.93	0.10	.	.	27.89	40.25
	3	1	6.52	5.72	0.47	4.82	1.70	0.00	4.36	2.05	0.18	142	24.2	27.86	25.89
		2	6.10	5.22	0.26	2.80	1.09	0.00	1.97	1.22	0.12	.	.	22.57	38.65
		3	5.87	4.73	0.22	1.50	0.61	0.00	1.46	0.81	0.08	.	.	21.48	42.56
4	1	1	6.27	5.46	0.61	7.59	2.81	0.00	2.55	2.45	0.23	393	25.1	48.75	0.50
		2	6.58	5.52	0.40	7.72	2.59	0.00	2.41	2.53	0.24	1179	27.8	50.89	0.40
		3	6.37	5.28	0.34	6.23	2.18	0.00	1.18	1.73	0.18	708	25.2	49.93	0.53
	2	1	5.70	4.50	0.33	2.16	1.37	0.25	1.52	1.69	0.15	884	26.8	45.83	18.58
		2	5.97	4.87	0.32	4.40	2.01	0.00	1.50	2.27	0.19	442	25.8	44.70	16.29
		3	6.20	5.02	0.23	3.19	1.56	0.00	1.21	1.59	0.13	354	27.7	32.13	41.78
4	3	1	6.16	5.12	0.91	3.33	1.84	0.00	3.91	1.68	0.15	442	27.6	43.35	4.93
		2	5.95	4.75	0.75	2.11	1.48	0.10	1.36	1.38	0.13	442	26.4	43.40	7.26
		3	6.30	5.20	0.77	5.19	2.09	0.00	2.67	2.16	0.17	442	26.3	46.16	2.81
5	1	1	5.97	4.86	0.62	3.72	2.19	0.33	4.89	3.27	0.21	353	33.6	54.89	3.34
		2	5.61	4.24	0.26	1.13	1.09	0.82	1.03	1.70	0.15	345	35.3	52.36	5.65
		3	5.62	4.17	0.19	0.33	0.95	1.60	0.94	1.29	0.12	140	26.2	60.35	3.89
	2	1	6.09	4.91	0.60	5.36	2.58	0.08	4.85	2.89	0.22	211	32.6	45.98	3.80
		2	5.34	4.12	0.62	1.40	1.16	0.59	0.00	1.43	0.13	223	33.1	53.71	4.25
		3	5.21	4.05	0.34	0.54	0.45	1.46	0.83	0.91	0.09	20	35.1	53.79	6.77
	3	1	5.83	4.42	0.57	2.49	2.87	0.17	5.10	3.75	0.27	.	.	55.48	1.45
		2	5.38	4.04	0.24	0.94	0.95	2.28	1.68	1.66	0.16	.	.	59.27	2.15
		3	5.35	4.09	0.21	0.47	0.34	2.73	1.19	1.22	0.12	.	.	62.12	1.66

1) 2. 3rd year, 3. 4th year, 4. 9th year, 5. 1st year
2) 1. lower slope, 2. middle slope, 3. upper slope
3) 1. 0-10 cm, 2. 10-20 cm, 3. 20-30 cm
4) Hydraulic conductivity.
5) Moisture content at 1000 kPa.

Table 3.5 Chemical properties and amount of ash

Field	Locations	EC (ms)	pH*) H2O	Na	K	Ca	Mg	NH4	P2O5 (mg/100g)	amount (ton/ha)
				-------(cmol(+)/Kg--------						
2	Lower-L[1)]	31.0	11.6	0.23	138.9	0.024	0.004	0.027	2.52	
	Lower-R[2)]	25.0	11.8	0.31	76.7	0.023	0.000	0.018	0.95	
	Middle1-L	17.3	11.4	0.30	71.4	0.007	0.038	0.021	6.91	
	Middle1-R	23.8	12.1	0.34	96.7	0.035	0.004	0.020	2.78	
	Middle2-L	40.0	11.9	0.27	186.4	0.077	0.008	0.019	1.61	
	Middle2-R	18.8	11.2	0.23	72.0	0.043	0.025	0.019	2.00	
	Upper-L	19.1	11.5	0.27	72.0	0.001	0.023	0.014	5.69	
	Upper-R	21.0	11.0	0.26	80.6	0.027	0.072	0.014	5.70	
										0.77
3	Lower-L	28.0	11.7	0.27	119.9	0.020	0.004	0.029	3.17	
	Lower-R	19.5	10.9	0.24	76.7	0.021	0.008	0.025	4.08	
	Middle-L	23.8	11.5	0.34	97.6	0.023	0.008	0.017	2.42	
	Middle-R	41.0	11.0	0.28	199.9	0.030	0.025	0.021	10.91	
	Upper-L	26.8	11.0	0.44	113.6	0.030	0.031	0.018	5.61	
	Upper-R	34.0	11.2	0.35	155.1	0.015	0.004	0.018	6.08	
										0.97
4	Lower-L	39.9	11.6	0.42	191.8	0.021	0.004	0.018	3.45	
	Lower-R	33.3	11.0	0.29	45.8	0.040	0.015	0.026	1.03	
	Middle-L	15.8	11.6	0.29	54.3	0.004	0.000	0.016	1.37	
	Middle-R	17.3	12.0	0.29	57.5	0.012	0.004	0.019	1.20	
	Upper-L	48.0	11.2	0.78	205.2	0.024	0.036	0.015	19.88	
	Upper-R	42.8	11.8	0.64	238.2	0.092	0.031	0.019	3.37	
										0.37
5	Lower	37.5	11.9	0.51	172.6	0.008	0.000	0.019	3.93	
	Middle	24.0	11.4	0.37	99.1	0.004	0.051	0.013	52.22	
	Upper	11.2	11.2	0.34	52.8	0.004	0.088	0.012	47.75	
										12.70

*) pH(H2O); ash to solution ratio of 1 to 5, 1)L;left side of the location
2)R;right side of the location

Table 3.6 Eigenvalues and proportions of variance to the total variance for derived principal components.

Principal components	Eigenvalue	Proportion	Cumulative percentage
Factor 1	4.141	0.460	0.460
Factor 2	2.464	0.274	0.734
Factor 3	0.944	0.105	0.839

Table 3.7 Rotated factor pattern for the first three principal components.

	FACTOR1	FACTOR2	FACTOR3
ExAl	-0.27	0.82	-0.07
pHw	0.20	-0.87	0.15
ExCa	0.86	-0.31	0.23
ExMg	0.83	-0.30	0.25
TC	0.95	0.07	0.07
TN	0.95	0.10	0.10
pF3.0	-0.01	0.46	-0.73
HD	0.34	0.12	0.82
Clay	0.45	0.81	0.01

Table 3.8 Factor score

Field[1]	Location[2]	Layer[3]	Factor1	Factor2	Factor3
2	1	1	1.27	-0.56	0.03
		2	0.24	-0.33	-1.17
		3	-0.29	-0.02	-1.10
	2	1	-0.30	-0.67	0.03
		2	-1.43	-0.66	0.72
		3	.	.	.
	3	1	1.04	-0.80	-1.04
		2	-0.09	-0.40	-0.92
		3	-1.17	-0.30	-1.03
	4	1	-0.52	-1.54	-0.10
		2	-1.98	-1.67	0.55
		3	-1.70	-1.13	-0.05
3	1	1	0.87	0.61	-0.39
		2	0.06	0.67	-0.95
		3	-0.15	0.58	-1.34
	2	1	1.31	-1.00	-0.38
		2	-0.80	-1.01	-0.87
		3	.	.	.
	3	1	0.18	-1.13	0.20
		2	.	.	.
		3	.	.	.
4	1	1	1.53	-0.30	0.58
		2	1.52	0.17	2.30
		3	0.52	-0.06	1.75
	2	1	-0.49	1.06	2.20
		2	0.55	0.11	0.84
		3	-0.38	-0.47	0.41
	3	1	-0.00	-0.07	0.68
		2	-0.60	0.24	1.06
		3	0.60	-0.21	0.75
5	1	1	1.52	0.88	-0.83
		2	-0.24	1.88	-0.53
		3	-1.10	2.23	0.94
	2	1	1.56	0.02	-1.15
		2	-0.42	1.57	-0.43
		3	-1.24	2.38	-0.86
	3	1	.	.	.
		2	.	.	.
		3	.	.	.

1) 2. 3rd year, 3. 4th year, 4. 9th year, 5. 1st year
2) 1. lower slope, 2. middle slope, 3. upper slope
3) 1. 0-10 cm, 2. 10-20 cm, 3. 20-30 cm

secondary forest is neutralized by a successive cropping. Based on the results of Nye and Greenland (1964), the pH value of upper 30cm increased from 4.6 before burning to 8.1 after burning, and dropped below 5.5 after one year cropping. This indicates that the effects of ash are exerted to the soils at 30 cm depth.

In this study, the pH value of the soils at 30 cm depth in F2, F3 and F4 did not drop below 5.5. This suggests that the effects of ash may be still continuing after one year cropping, in spite of both the depletion of basic cations by crops and the leaching of cations by rainfall. However, further study is necessary on the effects of ash.

3) Dryness factor is much higher in F4 than in F2, F3 and F5, suggesting that a tractor tillage would lead to a decrease of water holding capacity in a soil, since soil structure might be destructed, resulting in an increase of the macro pores.

3.3 Effect of soil Aluminum on maize

Before felling and burning forest soils may be acidic because fallow fields are subject to leaching. In slash and burn fields, ash obtained from burning the forest may come to ameliorate the soil acidity because ash provides a large quantity of exchangeable base.

The problem of soil acidity in the tropics has been studied by many researchers among whom the study of Sanchez *et.al* is especially excellent. They have proposed that the percent Al

saturation of the effective CEC (ECEC) is more useful parameter of soil acidity rather than the absolute amount of exchangeable Al. However, there still is no general agreement on Al saturation, as the parameter is used to estimate the likelihood of lower yields in acid soils.

Under an acidic condition, the value of Al-saturation seems to be more important than the absolute amount of exchangeable-Al in affecting crop growth. In case of low effective-CEC, Al-saturation would be high, even if the value of exchangeable-Al is low. In case of high effective-CEC in comparison with exchangeable-Al of high content, Al-saturation may be relatively small. If Al-toxicity were caused by the absolute amount of exchangeable-Al, toxicity would be observed in this case. In contrast, if Al-toxicity is caused by the degree of Al-saturation, when the ECEC is small, even a low exchangeable-Al may cause toxicity.

In general, improvement of the acid soils requires neutralization of the exchangeable aluminum, but farmers in the tropics cannot afford to buy any liming material. Therefore, ash obtained from burning forest help very materially to ameliorate the acid soil.

The following experiment was carried out to examine the effects of Aluminum toxicity on maize and also to evaluate mechanisms of Al-toxicity in acid soils.

3.3.1 Materials and methods

Pot experiments were initiated with Iya soil in Shimane prefecture and Yakuno soil in Kyoto prefecture to determine whether the absolute amount of exchangeable-Al or Al-saturation is the better criterion for predicting maize growth reductions. Two sites with very low soil pH, less than 4.3, were selected. The soils were acid sulfate soil and Andisols. The acid sulfate soil was taken from a polder area in Iya, and the Andisol from a pasture in Yakuno.

The properties of these soils are shown in Table 3.9. The data in Table 3.9 are average values of composite samples taken from each of the replicates before applying the treatments.

Soil pH was measured with a glass electrode pH meter with a 1:5 soil-water and soil-1N KCl suspension. CEC was determined by both the ammonium acetate extraction procedure and sum of cations. Exchangeable bases were extracted by NH_4OAC, and Ca, Mg were determined by atomic absorption spectrometry and Na and K by flame emission spectrometry. Exchangeable acidity was determined by titration of 0.01N H and successively exchangeable Al by titration of 0.01 NaOH after addition of 1M NaF.

Base saturation was calculated as; exchangeable bases/ exchangeable Ca, Mg, Na, K, Al and H. Total carbon and nitrogen were determined by dry combustion method using CN-corder. For the measurement of phosphate absorption coefficient(PAC), 25g soil was equilibrated with 50ml 2.5%$(NH_4)_2PO_4$, at pH7.0, for 24 hours. Phosphate remaining in solution was determined by the molybdo-vanadate method.

Soil texture was measured by the mechanical analysis and clay mineral were determined by X-ray diffraction analysis. Variable charge reaction was calculated as; (CEC-ECEC)/CEC.

The method of preparation used in the experiments are as follows:

	Soil	:	White quartz sand	Gross weight
Dilution	1	:	0	2.50 Kg
	2	:	1	3.75 Kg
	1	:	1	5.00 Kg

Liming : The final pH levels were 4.7(Lime-1) and 5.5(Lime-2), in addition to the untreated pH 3.89 of Iya soils and 4.35 of Yakuno soils(Lime-0). Buffer curves were determined for estimating the amount of $CaCO_3$ required to adjust soil pH to the desired levels in each soil.

The incubation study were selected for a greenhouse experiment using 'skyliner 95'a medium-maturing sweet corn variety. Soils were fertilized with N, P and K according to individual soil test; these fertilizers were added after the third mixture.

One maize plant per pot was grown; harvests were made after 3, 4, 5 and 8 weeks. Experimental design was a randomized complete block with two replications of each treatment.

3.3.2 Result and discussion

i)Effect on treatment for soils

The relationships between soil pH and exchangeable Al, soil pH and Al saturation for soils varying in liming and dilution are shown in Fig.3-4 and Fig.3-5, and chemical characteristics of the soils at each of three dilution and pH levels are listed in Table 3.10. Based on Fig.3-4.Fig.3-5 and Table 3.10, the following statements may be made.

1) In liming treatment plots, both of the amount of exchangeable Al and Al saturation increased with decreasing pH level on account of decreasing base saturation by liming. Thus, at the lowest pH level the amount of exchangeable Al and Al saturation showed a maximum.

2)In dilution treatment plots, while the amount of exchangeable Al decreased with increasing the dilution rate, neither base saturation nor Al saturation changes significantly, because CEC was simultaneously decreased by the dilution process.

3) The relationships between soil pH and concentration of exchangeable Al in soil solution, as well as the soil pH and Al saturation were not necessarily the same for Iya and Yakuno soils. This suggests the difference is caused by the charge properties of the soils, i.e. the Iya soil is dominated by permanent negative charges and the Yakuno soil by variable negative charge.

Table 3.9 Characteristics of Sample Soils

Soil	IYA	YAKUNO
pH(H_2O)	3.89	4.35
pH(KCl)	3.42	4.03
CEC(me/100g)	23.60	41.10
Ex.Ca	2.50	2.90
Mg	0.41	0.16
Na	0.06	0.05
K	0.77	0.56
Al	6.38	3.52
H	1.42	1.01
Acidity	7.80	4.53
BaseSat(%)	15.80	8.92
AlSat	55.30	42.90
TC	1.68	7.31
TN	0.13	0.34
Color	Gray	Black
PAC	880	2150
Texture	LiC	SiC
CS(%)	15.69	4.57
FS	22.72	11.36
Silt	28.60	45.91
Clay	32.99	38.15
Clay mineral		
Al-Vt	(-)	(++)
Ch	(-)	(+)
It	(+)	(+)
Kao	(+)	(++)
Qz	(+)	(++)
Mo	(+++)	(-)
VCR.	0.20	0.72

Abbrevietion: CEC measured NH_4AC at pH 7;
BaseSat,Sum of exch.bases/CEC; AlSat,exchAl/exchCa+ Mg+ Na+ K+ Al+ H; TC, Total Carbon; TN, Total Nitrogen
PAC, phosphate absorption coefficient; CS, coarse sand; FS, fine sand; Al-Vt, Al-vermiculite; ch, chlorite; It, illite; Kao, kaolin minerals; Qz, quartz; Mo, montmorillonite;VCR. variable charge ratio,CEC-ECEC/CEC

Table 3.10 Characteristics of Sample Soils after Treatment
(mean value of analysis made at 40 and 70 days after transplanting)

Soil/	Treatment[1]	pH(H_2O)	CEC	Ex.Base	B.S (%)	Ex.Al	Ex.H	AlSat (%)	T.C (%)
	D-0(1:0)	4.42A[2]	22.1A	6.46A	27.5A	3.45A	0.96A	29.8A	2.46A
	D-1(2:1)	4.45A	11.4B	3.48B	27.5A	1.98B	0.90A	25.8A	1.75B
I	D-2(1:1)	4.52A	8.3c	3.00C	25.9A	1.32C	0.77A	23.9B	1.55B
y									
a	Lime-0	3.97C	20.0A	2.78C	14.5C	4.88A	1.27A	53.3A	2.02A
	Lime-1	4.39B	16.3B	3.96B	24.8B	1.83B	0.93B	25.5B	2.17A
	Lime-2	5.02A	14.8B	6.16A	41.6A	0.04C	0.43C	0.7C	1.86A
	D-0(1:0)	4.87a[3]	47.4a	5.64a	12.0a	1.81a	1.17a	21.5a	5.82a
Y	D-1(2:1)	4.82a	21.1b	2.19b	10.2a	0.99b	0.83b	23.6a	3.92b
a	D-2(1:1)	4.92a	13.2c	1.48c	11.1a	0.81c	0.74b	25.2a	3.42c
k									
u	Lime-0	4.62c	27.1a	2.19c	8.1c	1.78a	1.25a	36.2a	4.43a
n	Lime-1	4.80b	25.8a	2.75b	10.4b	1.49b	0.94a	29.8b	4.57a
o	Lime-2	5.19a	28.8a	3.95a	14.8a	0.33c	0.55b	4.4c	4.16a

abbreviation: Ex.Base(me/100g),Na+ K+ Ca+ Mg; B.S, Base Saturation ; AlSat, Al Saturation; T.C, Total Carbon;
1)D: Dilution Lime: Liming
2),3) Different letters significantly different at p=0.05

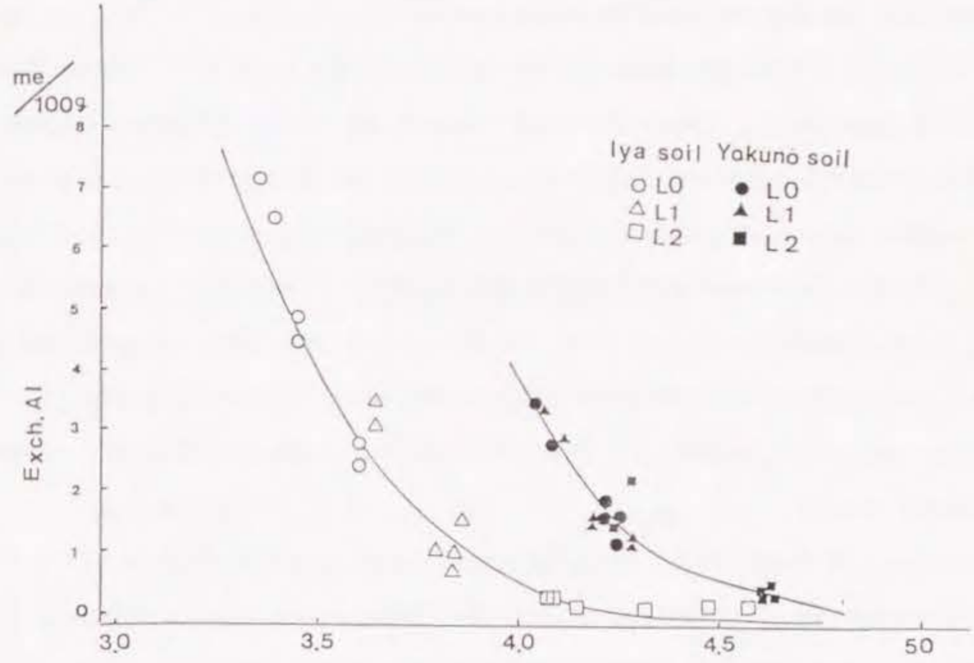


Fig 3-4 Relationship between soil pH and Exch Al

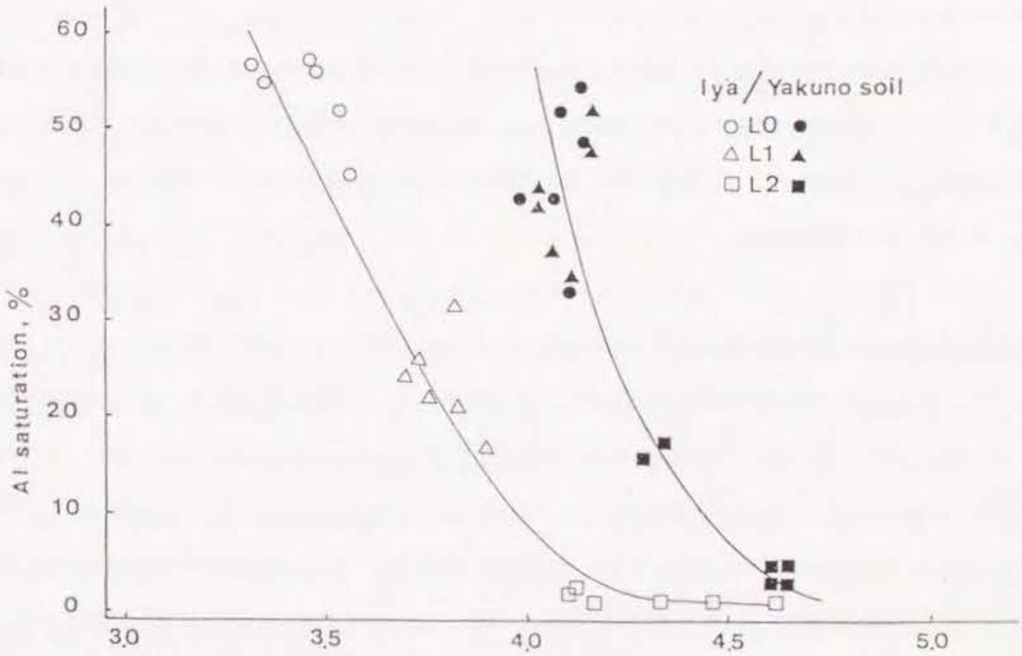


Fig 3-5 Relationship between soil pH and Al saturation

ii) Effect on treatment for maize growth

Data on maize biomass is shown in Table 3.11. Based on Table 3.11, in Iya soil, fresh and dry weight of maize shoots increased not only with increasing the amount of lime, but also with increasing soil dilution rate. On the other hand, in Yakuno soil, while shoot weight increased with increasing the amount of lime, the effect of dilution on shoot growth did not appear so strong. Root weight of maize increased with increasing the amount of lime, but the effect of dilution on root growth did not appear in either soil.

Relative growth rate (R.G.R) is defined as the incremental dry weight increase divided by plant dry weight per unit time. R.G.R in liming treatment increased with increasing the amount of lime, but in the dilution treatment it did not differ significantly from the control.

From these facts, it is suggested that treatment in these soils, shoot and root growth of maize appeared to be sensitive to liming but the effect of dilution on them was relatively small compared to that of liming.

iii) Effect of exchangeable Al and Al saturation on maize

Liming treatment for soils caused significant decreases in the amount of exchangeable Al and H, and Al saturation levels with increasing pH values, but also caused increasing base saturation levels. On the other hand, dilution treatment for soils was the cause of differences among the amount of exchangeable base, total carbon and nitrogen, significantly.

However, Al saturation, base saturation and pH value in dilution treatments were not significantly (Table 3.10).

Until recently, low pH itself had been considered as a growth inhibiter in acid soils until some solution culture experiments with low pH condition without including Al and Mn was reported by Aimi *et.al.* (1953) and Tanaka *et.al.* (1974). There are many reports about the harmful effect of soluble exchangeable Al on crops with lowering soil pH. In this study also, decreasing the amount of exchangeable Al caused of increased plant height (Table 3.12), weight and R.G R. In particular, it is markedly shown in Iya soil indicating a large difference of exchangeable Al. In this case, Al saturation in soils also decreased at the same time.

Contrary to this, maize growth with dilution treatment did not necessarily correspond to the amount of exchangeable Al, but was inversely correlated with the Al saturation level in soils. Moreover, in case of the same level of Al saturation and the difference of exchangeable Al, the weight of both top and root of maize showed little difference between dilution treatment plots, in particular, the weight of root was no significant.

Fig.3-6 shows relative fresh weight of maize as influenced by exchangeable Al and Al saturation in Iya and Yakuno soil. Based on Fig.3-6, the following statements may be made.

1) A change in exchangeable Al, while keeping Al saturation levels almost constant, had no apparent effect on the crops. 2) Under an acidic condition, the degree of Al saturation appears more important than the absolute amount of exchangeable Al in

affecting crop growth. This is in agreement with the experimental results of Sanchez *et.al.*(1976). They also reported that Al saturation levels in soil capable of supporting 90 percent of the maximum yields make a difference among soil characteristics, and crops.

Soils used in the experiment also varied in relation to soil texture, composition of clay minerals, charge properties of soils and liming response (Table 3.10), and differences between fresh weight of crops and Al saturation levels appeared when exchangeable Al was almost a constant(Fig.3-6). In the case of Iya soils, a strong negative correlation was observed between fresh weight and Al saturation ($r=-0.8762$), and while for Yakuno soils, the correlation was $r=-0.4604$.

The differences in crop response may be considered to appear by the differences of liming response for each soil. The Iya soil is characterized as a soil of permanent negative charge dominated by 2:1 clay minerals. Hence, while exchangeable Al decreases with increasing pH values by liming, base saturation becomes high level due to a very small change in CEC. Therefore, the effect of low levels of Al saturation on crops may be appeared stronger, compared with Yakuno soil.

On the other hand, the Yakuno Andisol is characterized as a soil of variable negative charge dominated by amorphous materials, and low base saturation due to a high content of humic substances. Therefore, base saturation levels did not become high with liming because effective CEC increased simultaneously with increasing pH values. In general, if a variable negative charge

soil, such as a volcanic ash soil, consists of 2:1-2:1:1 clay minerals, the presence of much exchangeable Al may be considered to affect crops seriously. In the case of the Yakuno soil, a volcanic ash soil, it is dominated by 2:1-2:1:1 clay minerals as shown in Table 3.9. As a result, while the amount of exchangeable Al increased with decreasing pH levels, Al saturation became high as the amount of exchangeable base decreased. However, the change in Al saturation level with liming was small due to the soil's large buffer capacity. Thus, differences between liming treatments appeared to be small.

Based on these considerations, the author suggests that a decrease in both exchangeable Al and Al saturation had a significant positive effect on the growth of maize. The difference in the crop growth was caused, among other factors, by the difference in charge properties of the soils; for in the acid soil with permanent negative charge, the effect of liming on the crop growth was prominent due to a sharp decrease in Al saturation, whereas that was not the case for the soils dominated by variable negative charge.

Aluminum toxicity is one of the major contributing factors to poor crop growth in acid soils. Under acidic conditions, the degree of Al-saturation appears more important than the absolute amount of exchangeable Al in affecting crop growth. This fact indicates that slash and burn agriculture without applying any fertilizer and lime is practiced by using ash obtained from burning forest with the idea of improving their fields.

Table3.11 Effect of Soil Treatment on Plant weight, Relative Growth Rate and T/R ratio

Treatment[1]		Whole	Top			Root			
Soil		F.W[4]	F.W	D.W[5]	R.G.R[6]	F.W	D.W	R.G.R	T/R[7]
	D-0(1:0)	120.1C[2]	83.0C	18.0B	30.9B	37.2A	4.7A	46.0B	3.8B
	D-1(2:1)	171.3B	127.0B	19.4AB	36.6B	44.5A	5.9A	55.6AB	3.3B
I	D-2(1:1)	209.1A	152.3A	24.5A	55.8A	39.3A	5.1A	60.7A	4.8A
y									
a	Lime-0	0.6C	0.4C	0.1C	5.7C	0.2C	0.04C	8.1C	2.5B
	Lime-1	100.3B	75.0B	13.0B	37.7B	25.2B	5.8 B	57.3B	4.5A
	Lime-2	400.2A	172.7A	48.8A	78.9A	95.6A	13.7 A	96.9A	3.6A
	D-0(1:0)	236.3b[3]	165.8ab	24.9a	87.8a	70.3a	4.7a	68.6a	5.3a
Y	D-1(2:1)	275.0a	195.0a	31.3b	80.9a	80.2a	6.1a	68.5a	5.1a
a	D-2(1:1)	237.8b	147.8b	30.8b	86.5a	90.0a	7.2a	76.5a	4.3b
k									
u	Lime-0	223.7b	145.8b	26.2b	73.2b	77.8b	6.1a	48.4c	4.3b
n	Lime-1	228.3b	155.0b	27.1b	86.3ab	73.3b	5.5b	94.4a	4.9a
o	Lime-2	297.2a	207.8a	33.8a	95.7a	89.3a	6.5a	70.8b	5.2a

1)D: Dilution Lime: Liming
2),3) Different letters significantly different at p=0.05
4)F.W: fresh weight(g) 5)D.W: dry weight(g) 6)R.G.R: relative growth rate
7)T/R: T-R ratio(Top dry weight / Root dry weight)

Table3.12 Effect of Soil Treatment on Plant Length (cm)

Treatment[1] /		6/17	6/24	7/1	7/4	7/15	7/22	7/29	8/5	8/12	8/20	MGR[3]
Soil					Iya Soil							
	D-1:0	25.0	25.1	24.6	24.6	*[2]						0.0
Lime-0	D-2:1	27.1	26.9	27.0	27.1	*						0.0
	D-1:1	23.1	23.1	22.7	20.6	19.9	20.0	24.3	25.8	55.6	66.3	0.0
	D-1:0	27.0	28.7	37.6	54.2	74.6	93.6	99.6	103.6	99.8	99.1	28.6
Lime-1	D-2:1	33.8	34.6	49.0	66.8	83.9	98.5	101.1	94.8	90.0	92.5	24.7
	D-1:1	28.9	35.2	53.8	75.1	94.2	106.9	113.1	120.0	124.2	126.4	30.7
	D-1:0	29.3	42.3	74.0	106.2	138.5	163.0	161.7	171.2	173.0	176.4	43.7
Lime-2	D-2:1	31.1	46.4	77.8	108.1	146.0	173.3	170.4	170.0	178.0	178.7	42.4
	D-1:1	27.8	54.1	88.8	124.7	162.6	187.0	201.9	198.3	197.9	198.3	49.1
Soil					Yakuno Soil							
	D-1:0	28.3	32.8	51.4	74.1	98.5	125.7	139.9	153.5	157.8	159.1	35.5
Lime-0	D-2:1	30.1	33.5	44.4	61.3	85.2	110.3	127.6	138.8	142.3	145.8	30.1
	D-1:1	32.1	39.7	55.0	72.8	98.0	123.8	135.5	165.8	166.2	166.8	31.2
	D-1:0	32.2	37.1	51.7	74.6	102.1	130.1	144.2	159.5	157.6	160.0	32.9
Lime-1	D-2:1	30.1	36.8	58.7	80.1	107.2	135.9	149.1	167.1	166.5	165.6	35.8
	D-1:1	32.1	41.7	58.1	74.8	105.7	130.8	148.2	174.3	177.9	177.2	32.7
	D-1:0	31.1	31.9	55.7	80.8	106.0	136.7	146.8	148.7	159.7	163.4	36.6
Lime-2	D-2:1	30.5	37.0	62.9	84.5	110.8	141.3	169.3	173.8	184.0	174.2	37.1
	D-1:1	30.7	42.9	61.9	79.1	108.0	135.3	155.4	181.3	185.2	182.4	34.9

1)D: Dilution Lime: Liming
2)*: withered
3)MGR: Growth Rate Mean value for 1～6 week

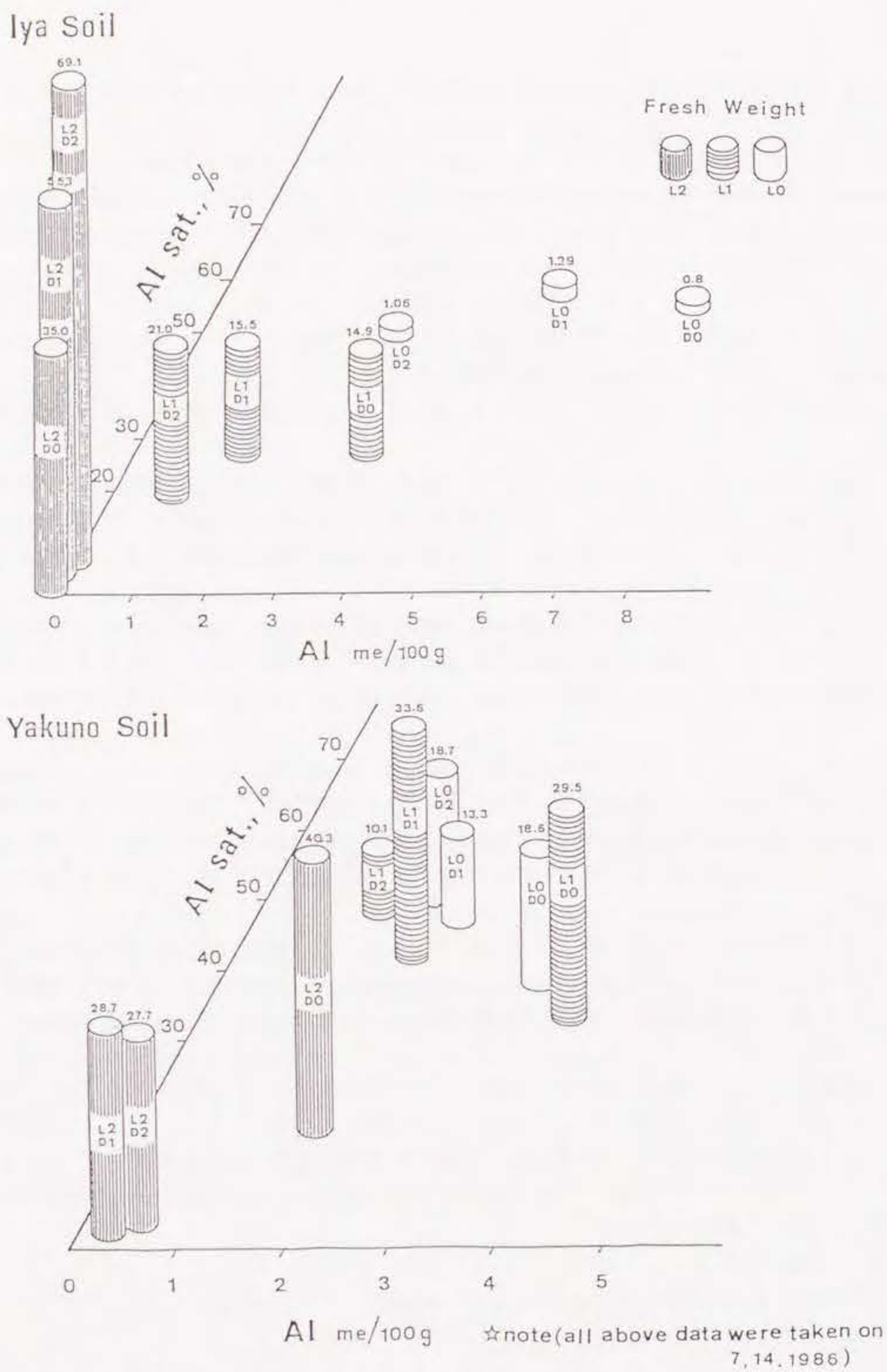


Fig.3-6 Relative Fresh Weight of Corn as Influenced by Exch Al and Al saturation

3.4 Measurement of run-off

3.4.1 Methods

Nine run-off plots were set on slopes 13-15° in the experimental field. The area of the plots was $10m^2$ (2m wide and 5m long). To minimize edge effect, galvanized plate 30 cm in width was used as a border and a border area around the plot was maintained in the same condition as the plot area.

Run-off water was collected into 3 plastic buckets with a capacity of 30 liters. The first one was fixed with a one seventh divider and the second one with a one third divider. Sediments in the run-off water were also collected. Run-off volume was measured with a graduated cylinder.

There were 5 treatments as follows:

4YR-NT = 4 years of no-tillage maize cultivation
4YR-TT = 4YR-NT, but with tractor tillage in the 3rd year
BUSH = 7 years under bush fallow
BURN = BUSH with slashing and burning
NT = BURN with 1st year no-tillage maize cultivation
TT = BURN with 1st year tractor-tillage maize cultivation

3.4.2 Results and discussion

Total rainfall during the growing season of maize from 23rd April 1991 to 10th August 1991 was 754 mm. The amount of run-off was 0.8 % to 6.4 % of the total rainfall, as shown in Table 3.13. The amount of runoff decreased according to treatment, in the following order: 4YR > NT > BURN > 4YR-TT > TT > BUSH (Fig.3-7).

The data in Table 4.13 show that in all plots only a small amount of the rain water was lost from the soil through run-off. This may be attributed to good soil structure (as low as 1.0 to 1.2 g/cc). Thus, soil erosion in the study area would not be a serious problem at this stage. However, cultural practices which can maintain this good physical property should be developed due to the tendency toward shortening fallow period in the area.

In the BUSH plot almost no runoff occurred. This indicates the main effects of 8 years of bush fallow on restoring structure of the soil, protecting the soil surface from raindrop impact and reducing the velocity of runoff. When the vegetation cover had been slashed and burnt, the amount of runoff significantly increased from 62 to 296 cu.m/ha, and, when maize had been planted (NT-plot), the figure slightly increased to 382 cu.m/ha.

Tractor tillage operation significantly reduced the amounts of runoff in both 4YR-TT and TT plots, from 480 to 198 cu.m/ha and 382 to 137 cu.m/ha, respectively. This may be mainly due to surface roughness of the soil caused by tractor tillage. In addition, continuous cropping tends to increase runoff as the largest amount of runoff was obtained from the 4YR-NT plot.

Table 3.13 The amount of runoff when rainfall higher than 5 mm

Date	Rainfall(mm)	Runoff(cu.m/ha)					
		4YR-NT	4YR-TT	BUSH	BURN	NT	TT
Apr.28	13	0	0	0	0	0	0
May. 3	20	3	3	0	2	3	3
4	6	0	0	0	0	0	0
5	71	154	66	10	55	66	15
7	7	0	0	0	0	0	0
8	20	19	8	5	13	13	7
9	35	40	12	0	16	16	7
16	45	40	12	7	41	35	10
17	30	9	9	0	25	20	6
18	10	3	4	0	4	5	2
21	7	2	2	0	1	1	1
23	23	16	7	1	12	14	4
27	11	1	2	1	2	2	2
Jun. 3	32	9	4	1	5	12	7
4	7	1	0	0	0	1	1
6	29	16	4	0	6	14	5
8	33	85	16	7	40	64	14
13	21	4	1	0	1	2	3
22	14	5	2	0	2	1	2
23	10	6	3	2	5	5	5
24	24	4	1	0	3	2	2
Jul. 2	11	1	0	2	2	2	1
17	25	7	3	3	5	13	5
21	8	3	1	2	3	2	2
22	135	44	33	18	44	79	27
30	15	2	1	1	3	4	2
Aug. 1	20	4	4	2	6	4	3
6	10	2	1	0	2	3	2
Total runoff		480	198	62	296	382	137
% of total rainfall		6.4	2.6	0.8	3.9	5.1	1.8

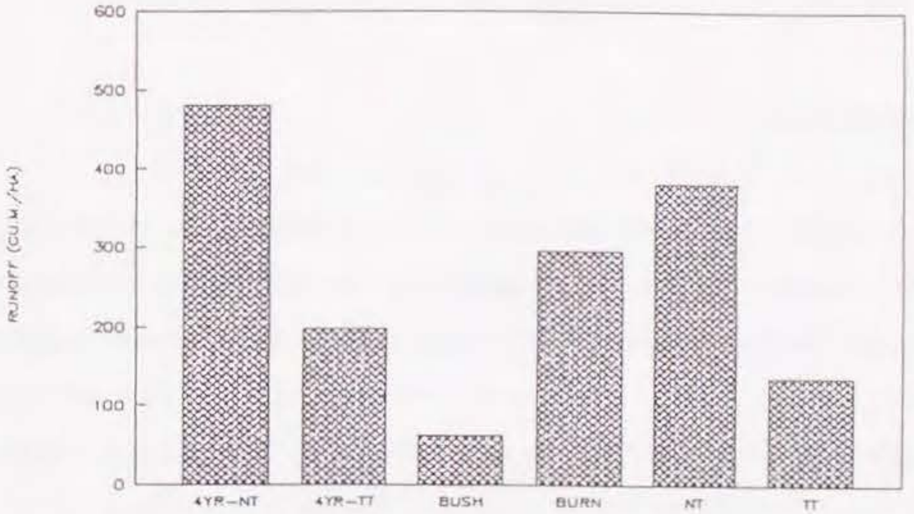


Fig.3-7 The amount of run-off during growing season

3.5 Cellulose decomposition in soils of slash and burn fields using Benchkote-paper

3.5.1 Method

One of the methods to estimate microbial activity in soils is by determining cellulose decomposition in soils. Measuring cellulose composition in soils by using Benchkote-paper (Whatmann Ltd., backed filter paper with polyethylene) was introduced by Tathuyama et.al (1984). Benchkote-paper was cut by knife in 20 X 30 cm squares, and weighed. The weight of a test paper ranged from 5.47 to 5.69 g per squares. They were vertically buried into 30 cm depth, preparing five replications, on April 6th, at the lower part of F2, F6NT and F6TT. They were sampled every month from May to August, and washed by water, and air-dried. Data are presented a decrease the weight of test paper as percent cellulose decomposition.

3.5.2 Results and discussion

Fig.3-8 shows cellulose decomposition of Benchkote-paper in F2 and F6NT. Percent cellulose decomposition after one month was 21 % in F2, and 56 % in F6NT. After three months it was more than 85 % in both F2 and F6NT. Hence, in the initial stage after burial, microbial activity in the soil of the first field just after clearing forest, F6NT, was much higher than that in F2,

successively for four years cropping. This suggests that the fallowing has a positive effect on the soil microbial population when compared to surface burnings. In the case of latter, it is referred to as partial sterilization.

On the other hand, Fig.3-9 shows percent cellulose decomposition in the soils which is under no-tillage and tractor tillage plots in F6. Percent cellulose decomposition under tractor tillage was lower than that under no-tillage, through the whole study period. The adverse effect of tractor tillage on microbial activity for cellulose decomposition by anaerobic micro-organisms may be attributed to the creation of soil macropores.

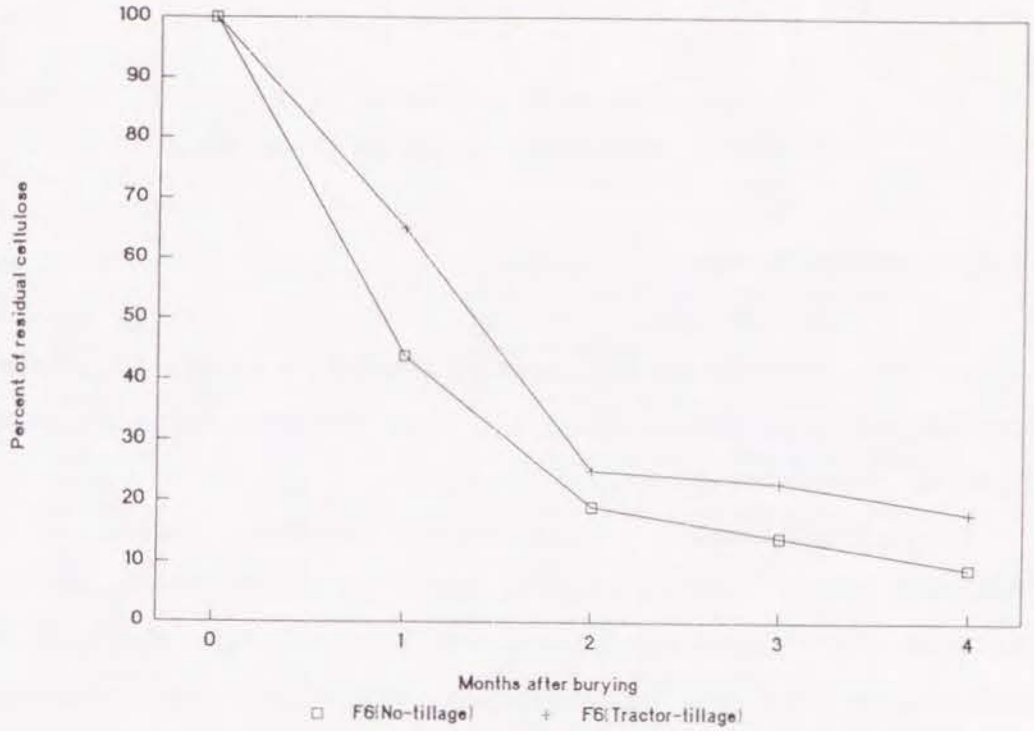
Based on these facts, the following statements may be made:
1) Successive cropping may decrease microbial activity for cellulose decomposition. Therefore, successive cropping may delay the breakdown of lignified plant and weed residues. 2) Tillage with mixing the soils and creations soil macropores restrains the activity of anaerobic micro-organisms. However, the relationship between these facts and plant growth are still unclear points.

3.6 Conclusion

Soil chemical fertility in the study site was markedly varied dependent on the locations of slope, compared with the variation by successive cropping. This variation was caused by the difference of effective soil depth and gravel content in the soil, i.e., soil chemical fertility was high in lower part of slope having thicker solum and low gravel content, and was low in upper part of slope having shallower solum and high gravel content.

Ash obtained by burning a forest is not only effective for soil fertility, but also ameliorated the soils that have been fallowed are subjected to acidification. This suggests that the basic cation is included ash affect Al-saturation level in acid soils.

Tractor tillage was effective for a decrease of run-off by making macropores in the soil, whereas water holding capacity of the soil was reduced. The microbial activity determined with cellulose decomposition was low in successive cropping field and in tractor tillage plot. This may be caused by aerobic conditions in these soils.



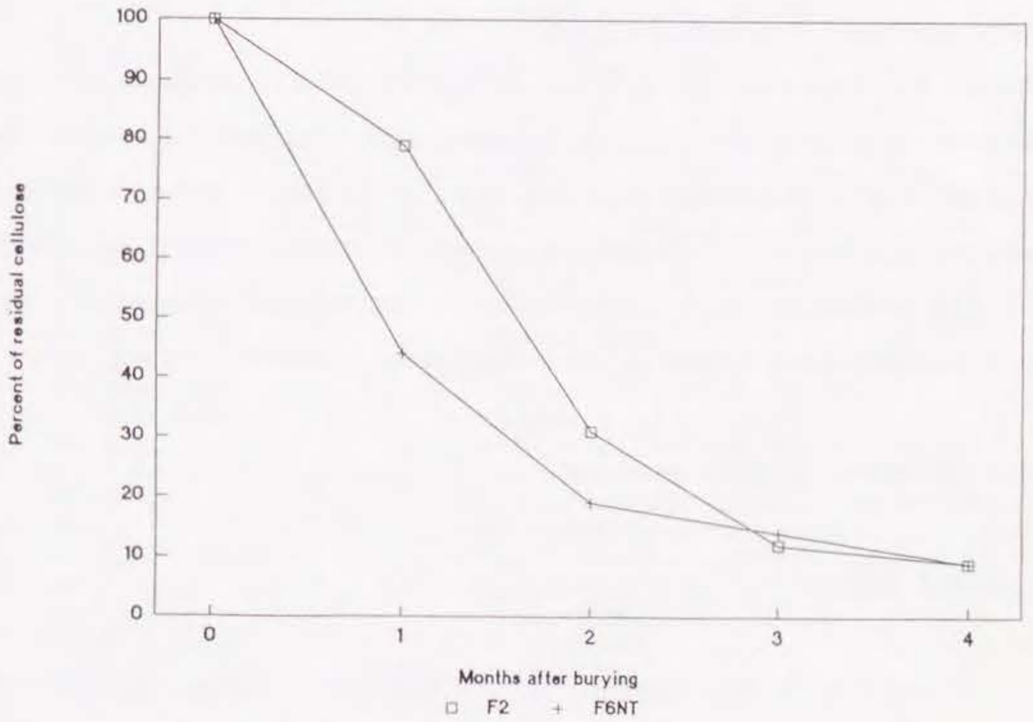


Fig.3-8 Percent of residual cellulose

CHAPTER 4 Vegetation cover in study site

4.1 Secondary forest

The secondary vegetation cover of F5 and F6 before felling and burning was investigated which had been fallowed for 8 years and 9 years, respectively.

Under the climatic conditions as described above, "Mixed Deciduous Forest" stands as a natural vegetation, which has been replaced almost entirely by secondary forest due mainly to the shifting cultivation. In this study, the vegetation cover of F5 was surveyed in March 1991, before starting the experiment. Both in F5 and F6, the landform was faced to the Northwest and the slope gradient was ranging from 11° to 26°.

Table 4.1 listed tree species observed in F5, indicating that Bambusa spp (Mai-pai in local name) are dominant, followed by Croton spp., Terminalia graucifolia Craib., Acacia comosa Gangnap., Albizia lucida Bebeth., Lagerstroemian tomentosa Presl. and Dipterocarpus tuberculatus Roxb. Hence, the vegetation type in the study area would be semi-deciduous seasonal forest.

4.2 Dynamics of weed species

4.2.1 Method

To elucidate the succession and characteristics of weeds in

Table 4.1 Tree species observed at a secondary forest

Local name in Thai	Scientific name
Mai Pai	*Bambusa* spp.
Term	*Bischofia javanica* Bl.
Saa	*Brossonetia papyrifera* Vent.
Haa	*Syzygium cumini* Skeels.
Takean	*Hopea* spp.
Long Lang	*Cassia fitula*
Doeng Dong	*Shoutenia hypoleuca*
Kae Pa	*Dolichanedrone serrulata* Seem.
Sao	*Lagerstroemia tomentosa* Presl.
Muad	*Helicia* spp.
Pradu	*Pterocarpus macrocarpus* Kurs.
Haen	*Terminalia graucifolia* Craib.
Cum	*Garuga pinnata* Merr.
Pluay	*Homalium* spp.
Madua	*Ficus spp.*
Som poi	*Acacia rugata* Merr.
Ja muad	*Bryonia adorescence* Bl.
Ruk	*Melanorrhoea* spp.
Poe Pa	*Sterculia* sp.
Plao	*Croton* spp.
Tiuu	*Cratoxylium* spp.
Oi Chang	*Lannea coromandelica* Marr.
Nam han	*Acacia comosa* Gagnep.
Pii	*Dalbergia cana* Grah.
Po Doeng	*Antidesma montanum* Bl.
Po Daeng	*Sterculia guttata* Roxb.
Yom	*Chisocheton siamensis* Craib.
Tao Dao	*Similax lanceifolia* Roxb.
Ten	*Duabanga sonneratioides* Ham.
Sam tao	*Polyalthia viridis* Craib.
Kaew	*Himusops elengi* Linn.
Lumyai Pai	*Walsula* spp.
Kae	*Albizzia lucida* Benth.
Ngao(Teng)	*Shore obtusa.*
Nguu Pa	*Bombax* spp.
Ma kok	*Spondias pinnata* (L.F.) Kurz.
Ma kok Don	*Schrebera swietenioides.*
Ma kok Fon	*Turpinia pomifera* Dc.
Ta Lo	*Schime willichii* Korth.
Ma Kahm Pom	*Albizzia odratissima.*
Yong Nu	*Dipterocarpus turbinatus* Gaertn.f
Mog	*Parinari anamense* Hance.
Tueng(Pluang)	*Dipterocarpus tuberculatatus* Roxb.
Ko	*Castanopsis* sp.
Sao Pa	Unknown
Kled	Unknown

each field, the species and number of coppice shoots and weeds were examined and their above and underground biomass were measured both in the dry and rainy season in 1991 and 1992. The sample weeds were collected from three $4m^2$ quadrate in the upper, middle and lower part of the slope in each field. First of all the weeds were classified on their species and the total biomass was measured after air-dried. The weed species was described as local name in Thailand and scientific name as shown in Table 5.2.

4.2.2 Results and discussion

The weed species in the study fields were classified into herbaceous weeds and coppice shoots with a total of 70 species consisting of 12 species of herbaceous species and 58 woody species (Table 4.2).

In the dry season, number of species of herbaceous weeds and coppice shoots were 8 and 24, respectively, with a dominance of *Eupatrium odoratum* in F2, F3 and F4. On the other hand, in the rainy season there were 12 and 48 species of herbaceous weeds and coppice shoots, respectively, and *Eupatrium odoratum* was replaced by *Ageratum conyzoides* as a dominant species. In addition, *Crassocephalum rubens* and *Imperata cylindrica* were observed in all the fields. Particularly, in F2 *Imperata cylindrica* and *Ageratum conyzoides* were almost the same in number. Thus seasonal changes in both the number of weed species and dominant species were conspicuous, in coincidence with the study in Northern Thailand by Nakano(1978).

The number of weed species in each field varied from 17 to 22 in the dry season and from 17 to 25 in the rainy season(Fig.4-1). In the dry season, the number of weed species specific only to F2, F3 and F4 was 6, 13 and 5, respectively. However, in the rainy season, the figures in F2, F3, F4 and F5 were 7, 7, 5 and 14, respectively. Thus, the occurrence of weed species was quite variable from one field to another. This would partly be attributed to different land-use histories, such as frequency of burning, weeding and cropping.

In the rainy season, the total number of weeds was largest in F2, followed in descending order by F3, F4 and F5, while the proportion of coppice shoots was in the reverse order except F5(Fig.4-2). Moreover, based on Fig.4-3, the ratio of the number of herbaceous weeds to that of coppice shoots was larger in F2, F3 and F4 than in F5, suggesting that tree regeneration is inhibited by successive utilization of the land by burning.

Table 4.3 shows the percentage of the dominant species in each field. In the dry season, the dominant species occupied from 49 to 57 %, whereas in the rainy season the figures went up to more than 65 % for F2, F3 and F4. However, the figure for F5NT and F5TT in the rainy season were only 38 % and 31 %, respectively, suggesting a higher ecological diversity in F5, which has been used for cropping only once after clearing.

In Both the dry and rainy season, total dry matter of weeds in F2 was higher than that in the other fields (Fig.4-4). This would be attributed to root biomass especially *Imperata cylindrica* which propagates by rhizomes and occupies a large area in the field. According to Nye and Greenland (1960), this weedy species in the Dry Forest and Savanna zone in Africa stores the considerable weight of roots and stolons in a soil.

4.3 Conclusion

Vegetation type in the study area would be classified into semi-deciduous seasonal forest.

Dominant weed species in the study site was *Eupatrium odoratum* in the dry season, whereas *Ageratum conyzoides* replaced *E. odoratum* as a dominant species in the rainy season. *Imperata cylindrica* also which has been regarded the weed as serious problem infested broadly in the fields.

Herbaceous weeds in successive cropping fields obviously dominated in a total number of plant compared with coppice shoots, whereas coppice shoots in one year cropping field dominated. These facts suggest that tree regeneration in fallow is suppressed by burning in every year and by successive cropping.

Table 4.2 Herbaceous weeds in dry and rainy season of 1991.

No.	Herb weed name: Local name: Dry season	Local name: Rainy season	Scientific name
1	Saap suea	Saap suea	*Eupatrim odoratum*
2	Saapraeng saapkaa	Saapraeng saapkaa	*Ageratum conyzoides*
3	Yaa khaa	Yaa khaa	*Imperata cylindrica*
4	Yaa nepia	Yaa nepia	*Pennisetum purpureum*
5	Maiyaraap thao	Maiyaraap thao	*Mimosa invisa*
6	Pak Meo	Pak Meo	*Crassocephalum rubens*
7	Phak phet	Phak phet	*Amaranthus viridis*
8	Maamui	Maamui	*Mucuna pruriens*
9		Yiew suea	*Erigeron canadensis*
10		Yaa khachyon chop	*Pennisetum predicellatum*
11		Pak plaap	*Commelina benghalensis*
12		Yaa hae muu	*Cyperus rotundus*

Reqenarated tree name

	Dry season: Local name	Dry season: Scientific name	Wet season: Local Name	Wet season: Scientific name
1	Khuad Lao		Khuad Lao	
2	Mai Pai		Mai pai	*Bambusa* spp.
3	Nam Nae		Nam Nae	
4	Kam		Kam	*Garuga pinnata* Roxb.
5	Ma Phai		Ma phai	
6	Pan co Kuwan		Pan co Kuwan	
7	Poa pa		Poa pa	*Steruculia* sp.
8	Sakkaraat		Sakkaraat	
9	Sam Pii		Sam Pii	*Dalbergia cana* Grah.
10	Seo Pa		Seo pa	
11	Tao Kon		Tao Kon	
12	Tao Dao		Tao Dao	*Similax prolifera* Roxb.
13	Tiu		Tiu	*Cratoxilium* spp.
14	Tod maa		Tod maa	
15	Tub Kuwai		Tab Kuwai	
16	Haa	*Syzygium cumini* S.	Kluay	
17	Pub Pa	*Croton* spp.	Boog	
18	Lam Yai	*Walsula* spp.	Born Hom	
19	Term	*Bischofia javanica* Bl.	Chanang Pa	
20	Lep Meo		Dear Pong	
21	Geo Foi		Ka Mon	
22	Saa	*Brossonetia P.* Vent.	Hing Men	
23	Nat		Kamin Pa	
24	Keo Peng		Khai Tao	
25			Kham Krua	
26			Khem	
27			Khaw jii	
28			Kirow Man Klaep	
29			Kluab Pa	
30			Maet	
31			Ma Noi	
32			Mah Mae Kam	
33			Ma Doog	
34			Makheo Pong	
35			Mai Pii	
36			Makham Pom	*Albizzia odratissimia*
37			Mao	
38			Mou	
39			Nam Jii	
40			Namnom Rachasee	
41			Rieng Phai	
42			Tao Yang	
43			Tog	
44			Tong Kong	
45			Teud Meo	
46			Eong Mai Na	
47			Yaap	
48			Yioy	

Table 4.3 Changes in the occurrence of dominant weed species

Field	Dry season	%*)	Rainy season	%
F-2	*Eupatrium odoratum*	57	*Ageratum conyzoides*	78
F-3	*Eupatrium odoratum*	49	*Ageratum conyzoides*	67
F-4	*Eupatrium odoratum*	55	*Ageratum conyzoides*	65
F5-NT			*Ageratum conyzoides*	38
F-5TT			*Ageratum conyzoides*	31

*:Percent of dominant species for all weeds, in number

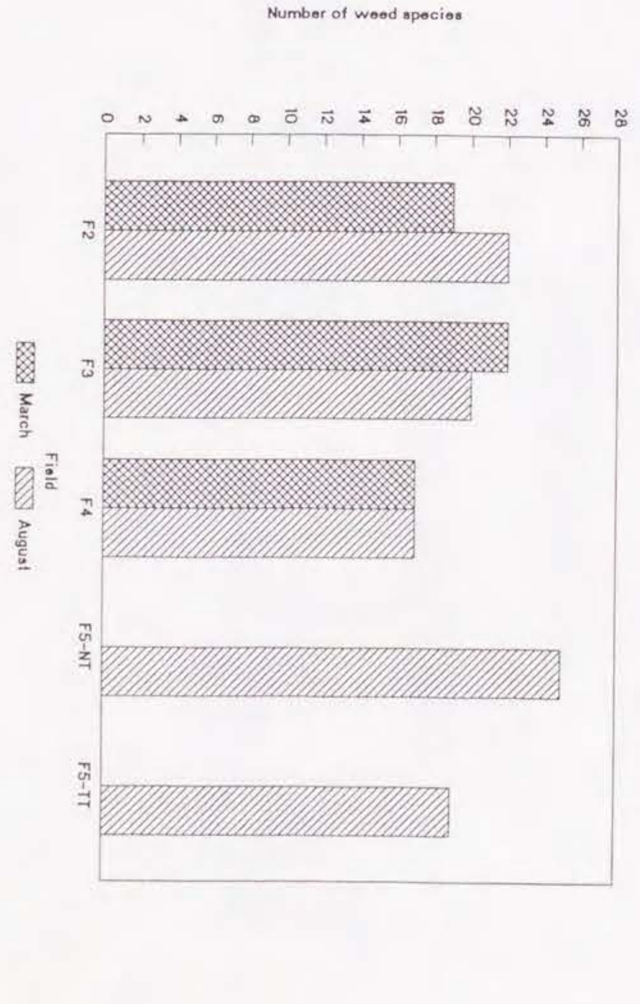


Fig.4-1 Seasonal changes in occurrence of number of weed species

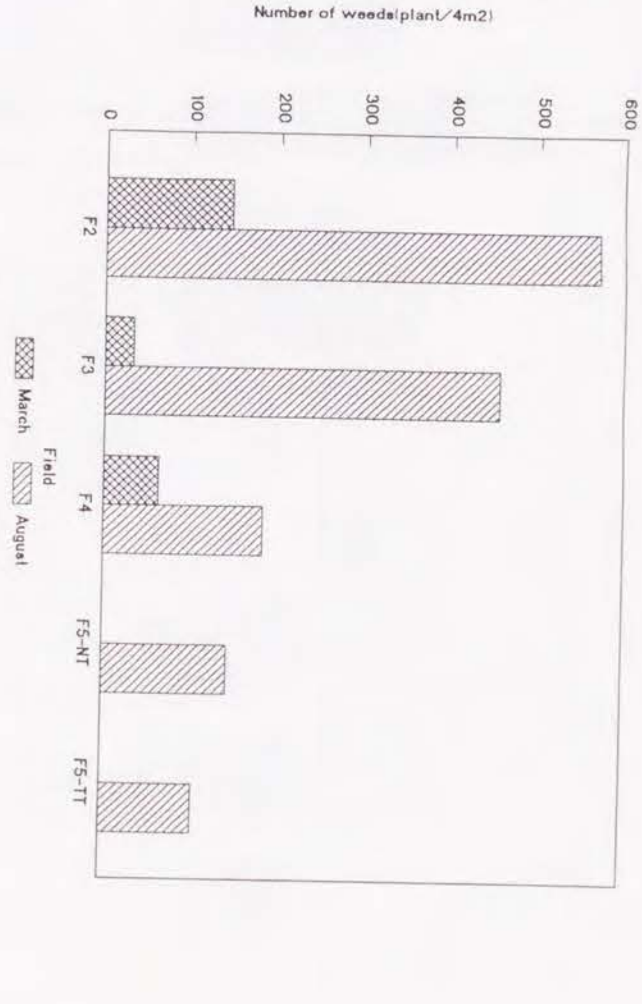


Fig.4-2 Seasonal changes of number of weeds

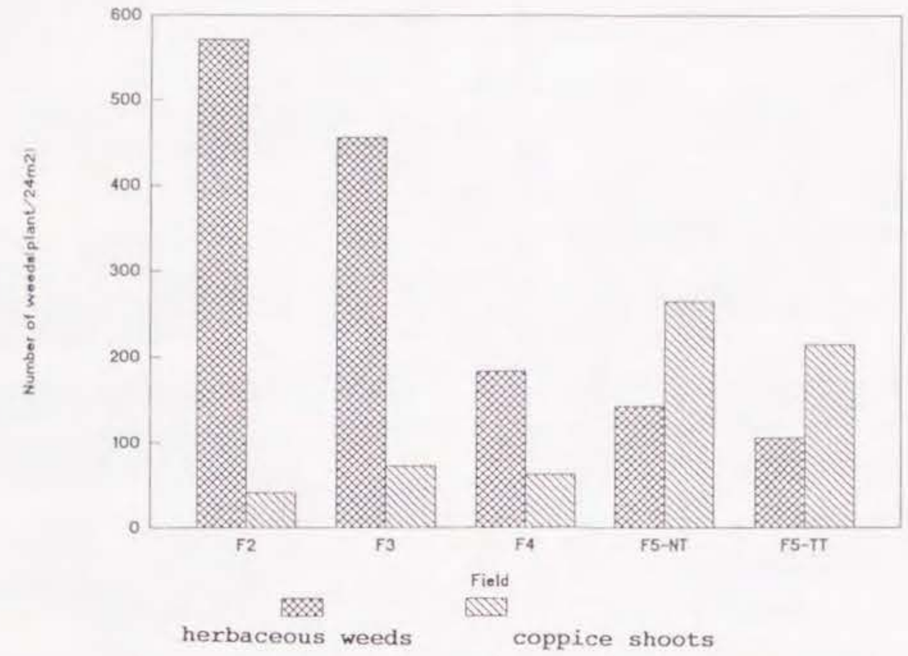


Fig.4-3 Number of herbaceous weeds and coppice shoots

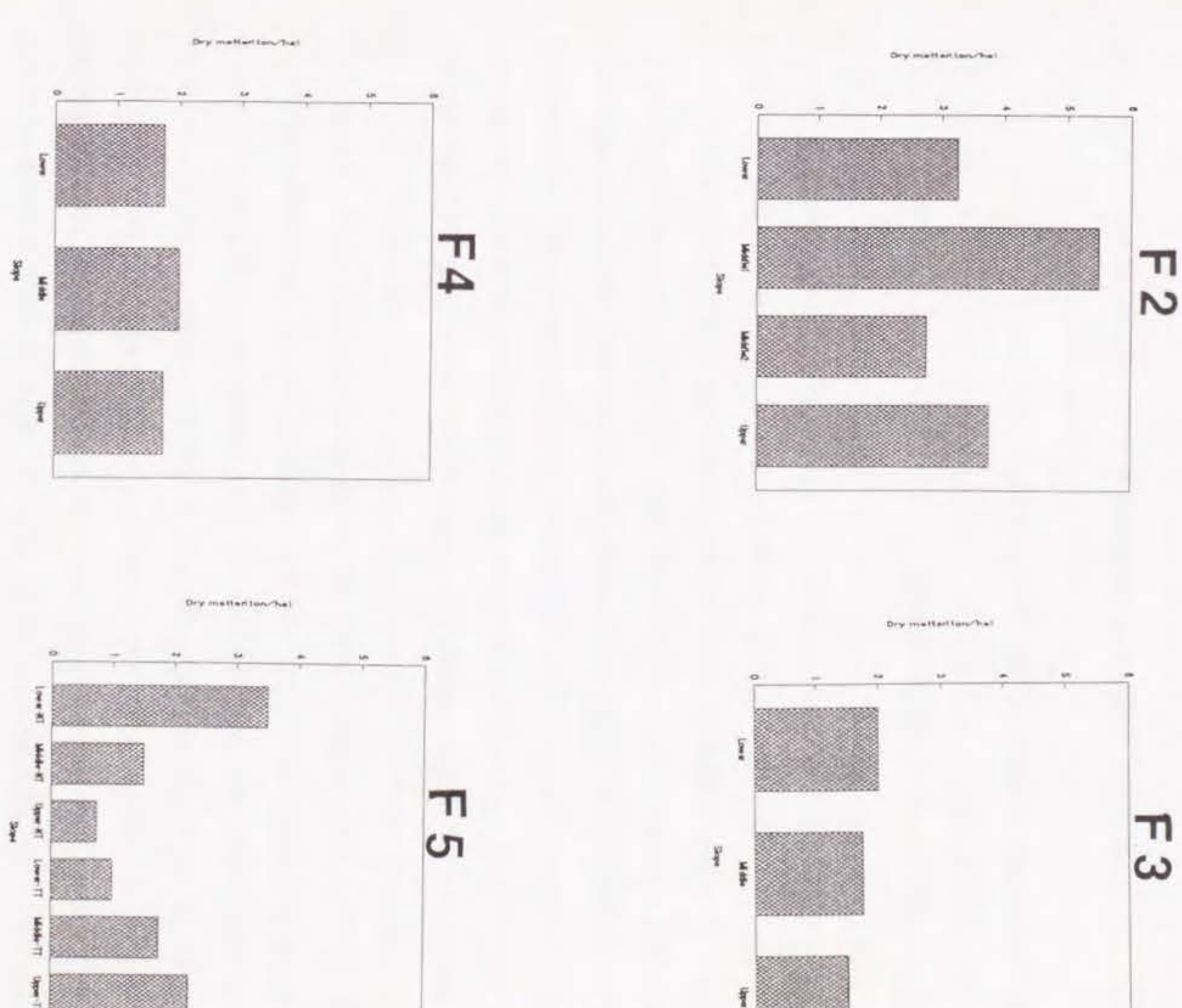


Fig.4-4 Dry matter content of weeds in each slope

CHAPTER 5 Crop productivity in study site

5.1 Characteristics of crop production

5.1.1 Materials and methods

To evaluate the productivity in the fields of the different land-use histories, crop yield as well as top and root dry matter was measured in the rainy season in 1991 and 1992.

In 1991, Suwan No.1, a common variety of maize (*Zea mays*) in Thailand was planted at a spacing of 80 cm with 3 plants per hill in accordance with farmers' practice due to evaluate the productivity with the present practice in F2, F3, F4 and F5. The planting date was through April 24th and 25th, and crop was harvested from August 6 to 8th.

In 1992, the experiment of single-cropping with farmer's practice was not only carried out in F2, F3, F4 and F5, but also the experiment of intercropping with maize, upland rice and soybean was carried out for the purpose of comparison of agronomic characters under single-cropping and intercropping in F6. Syu Daeng and Syu Maechan, a late-maturing variety of upland rice (*Oryza sativa.L*), and Sou Chou 5, a medium-maturing variety of soybean (*Glicine max Merrill*) in Thailand and Tamahomare, a late or medium-maturing variety of soybean in Japan was used in F6 as using an experimental field. The planting date was through May 26th and 27th because we had little rain from April through

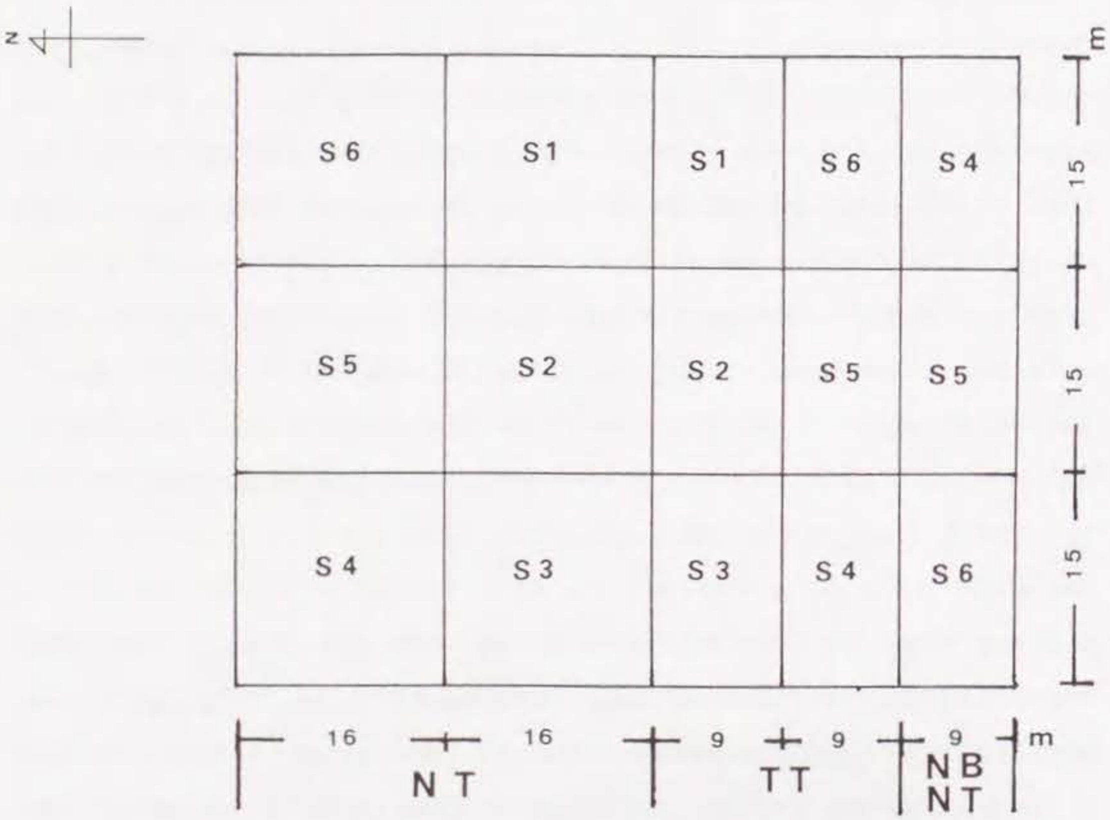
May in 1992. The crop growth was measured on August 10 - 15 and the crop was harvested on September 10-12 for soybean and on October 1 - 5 for maize and upland rice.

The layout of the experimental plots in F6 is shown in Fig.5-1. There were 6 agronomic plots. S1, S2 and S3 were used for the intercropping experiments, and S4, S5 and S6 were used for the single-cropping experiments. In the intercropping plot, S1, upland rice at a spacing of 25 cm with four rows and maize in rows parallels to the contour 75 cm apart and the distance between hills in a row was 25 cm were planted and S2, both upland rice and soybean were planted at a spacing of 25 cm with four rows and 2 rows, respectively, and S3, maize and soybean were planted in the same spacing of S1 and S2. In the single-cropping, upland rice in S4 and soybean in S6 was planted at a spacing of 25 cm with 5 plants per hill and one plant per hill, respectively, and S5, maize was planted in the same spacing of maize in S1 and S3.

Three subplots were set up, i.e. NT, cropped to each crop with no-tillage or minimum tillage as a traditional tillage after burning, TT, cropped to each crop with tractor tillage after burning, and NB, cropped to maize only with no-tillage and no-burning. In all plots fertilizer was not used.

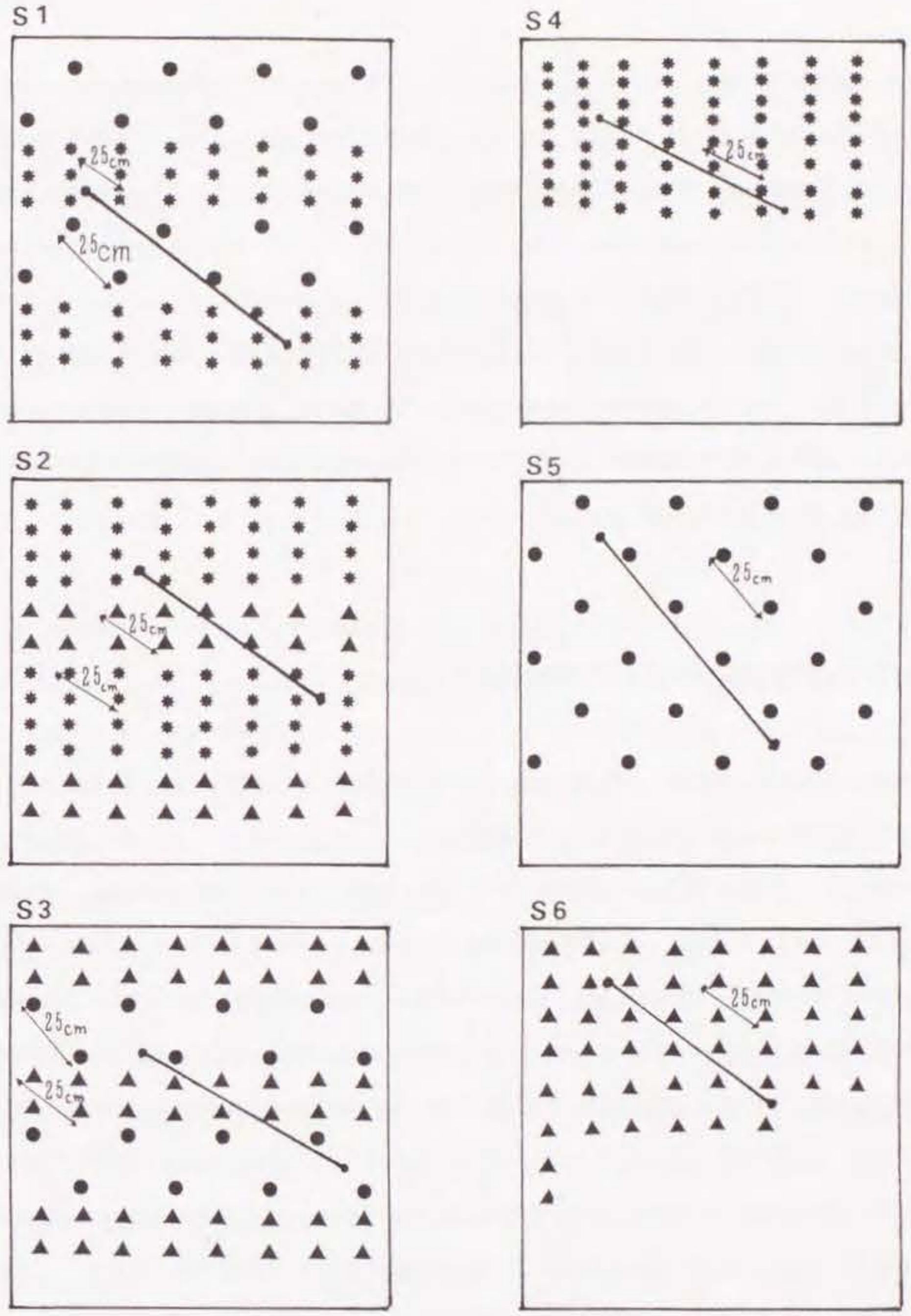
Plant height of maize and rice in F6 was measured on 32 plants and 60 plants per subplot for single-cropping, respectively. Leaf color of the crops was determined by using chlorophyll meter on 60 leaves per plot. The grain and top part of crops were collected from three or four 25 m^2 quadrates at the slope of

Cropping systems
S1:Intercropping with maize and upland rice
S2:Intercropping with upland rice and soybean
S3:Intercropping with soybean and maize
S4:Single-cropping with upland rice
S5:Single-cropping with maize
S6:Single-cropping with soybean



NT: No-tillage
TT: Tractor tillage
NBNT: No-tillage & No-burning

Fig.5-1a Layout of the experimental plots



●: maize
✱: upland rice
▲: soybean
•—•: Sampling profiles

Fig.5-1b Diagrammatic illustration of the experimental design upper, middle and lower in F2, F3, F4 and F5, whereas in F6 they were collected from three 16 m2 quadrates in each treatment plot. The root samples were collected from three hills in each sampling plot. After collecting the samples, they were weighed after drying at 70°C. The dry matter content yield of grain, top and root were summed up as total biomass of plant. Sampling of weeds as well as crops were performed in same place. Leaf color of crops in each treatment was measured by chlorophyll meter (SPAD-502 type, Minolta Ltd.).

5.1.2 Result and discussion

i) Characteristics of maize production in farmers fields of different land-use history

Data in Table 5.1 show dry matter yield of grain, top and root of maize and weeds sampled in August 1991. Significant differences among them in fields were observed, but the order was not necessarily related to the land-use history, since F5TT had the largest grain yield, followed in a descending order by F4, F3, F5NT and F2 (Fig.5-2). The highest yield of F5TT may be ascribed to the effect of tractor tillage and the high amount of ash addition resulted from burning in F5 (Table 3.5). On the other hand, the lowest yield in F2 was apparently not only cause by a low amount of ash addition as shown in Table 3.5, but also by serious growth inhibition of maize by weeds, as shown in Fig.6-3. Thus, a clear tendency that crop yield decreases with

successive land utilization was not found in this study.

Fig.5-4 illustrates a decrease in grain yield of maize with increasing slope gradient, indicating an effect of topography on crop production.

The root number of maize was small in the place of shallow soil and/or the steep slope gradient, such as in the middle part of F2 and F4, and upper part of F2 and F3 (Fig.5-5), where most of the roots were concentrated in the layer of 0-20 cm soil depth, because the penetration into subsoil was suppressed by the bed rocks.

The relationship between a top weight, a root weight and grain yield of maize, and the factor scores of every soil layer(Table 3.9), which are reflecting soil physico-chemical properties before burning was examined by a correlation analysis, and the pairs with a significant correlation were shown in Fig.5-6. These figures show that root part, top part and grain yield are significantly correlated with Factor 1, i.e., soil chemical fertility factor, suggesting that soil chemical fertility at 20 - 30 cm depth greatly influences crop growth and grain yield.

Furthermore, it is indicated that the tractor tillage in F4 is effective for promoting crop growth. Although the amount of ash added is much higher in F5NT than in F2, F3 and F4, crop does not grow well(Table 5-1). As this is related to lower fertility in deeper soil layer in F5NT before burning, the soil chemical fertility is not considered to be ameliorated by the addition of ash in a few months, as shown in Fig.5-6, Fig.5-7 and Fig.5-8.

Since a traditional tillage with a successive cropping can ameliorate the soil chemical properties at deeper layer, the most serious factor in lowering soil chemical fertility in this area is considered to be high soil gravel content, which are also related to a shallow soil occurring on a steep slope.

As regards weeds in Table 5.1, F2 is significantly high as compared with others. This is because F2 is located close to a fallow field and hence directly affected by propagation of weed species. In F2, the growth of crops in a gentle sloping land is superior to that of weeds whereas it is inferior in a steep sloping land. This suggests that weeds are more tolerant to adverse condition, such as low fertility at a shallow solum.

If land productivity is defined in terms of the total biomass production including weed and crop, the difference between the experimental fields was not so significant (Table 5.1), suggesting that the land productivity does not decrease rapidly as a successive cropping is proceeded. Thus, since weeds can grow even in areas unsuitable for crop growth and build up relatively large amount of organic matter, they conserve the fine earth fraction from soil erosion and hence sustain soil fertility.

Based on this consideration, we conclude that it is better to grow weeds at a steep sloping location as a live or dead mulching material than to throw them away.

Table 5.1 Grain yield and biomass of maize and weeds in each sampling point

Field	Biomass (ton/ha)						
	maize			Weeds	Total[1]	Weeds/Total (%)	Slope[2] gradient
	Grain	Above-ground	Under-ground				
F2							
Lower	2.97	3.73	0.79	3.17	10.66	29.7	16
Middle1	2.19	2.70	0.49	5.42	10.80	50.2	28
Middle2	1.80	2.79	0.61	2.76	7.96	34.7	23
Upper	1.52	2.85	0.54	3.84	8.76	43.8	29
Average	2.12c	3.02c	0.61c	3.80a	9.55bc	39.8	
F3							
Lower	3.25	3.83	1.04	1.96	10.09	19.4	23
Middle	3.41	4.06	0.88	1.67	10.02	16.7	25
Upper	3.56	3.99	0.71	1.38	9.64	14.3	22
Average	3.41b	3.96b	0.88b	1.67b	9.92ab	16.8	
F4							
Lower	3.18	3.73	0.89	1.67	9.47	17.6	12
Middle	3.63	4.07	0.74	2.04	10.48	19.5	15
Upper	4.16	4.03	1.20	1.75	11.15	15.7	11
Average	3.66ab	3.94b	0.95ab	1.82b	10.37ab	17.6	
F5NT							
Lower	3.02	3.25	0.67	3.38	10.32	32.8	14
Middle	1.97	2.42	0.39	1.50	6.28	23.9	16
Upper	2.38	3.06	0.65	0.75	6.84	11.0	21
Average	2.46c	2.92c	0.57c	1.88b	7.83c	24.0	
F5-TT							
Lower	4.51	4.10	0.61	1.00	10.22	9.8	15
Middle	4.11	4.90	1.11	1.63	11.75	13.9	16
Upper	3.83	5.10	1.37	2.13	12.43	17.1	21
Average	4.15a	4.72a	1.03a	1.59b	11.49a	13.8	

Different letters within a column for the comparison between five fields show significant difference at p=0.05

1) Total: sum of crop and weed biomass, 2) Slope gradient in degree.

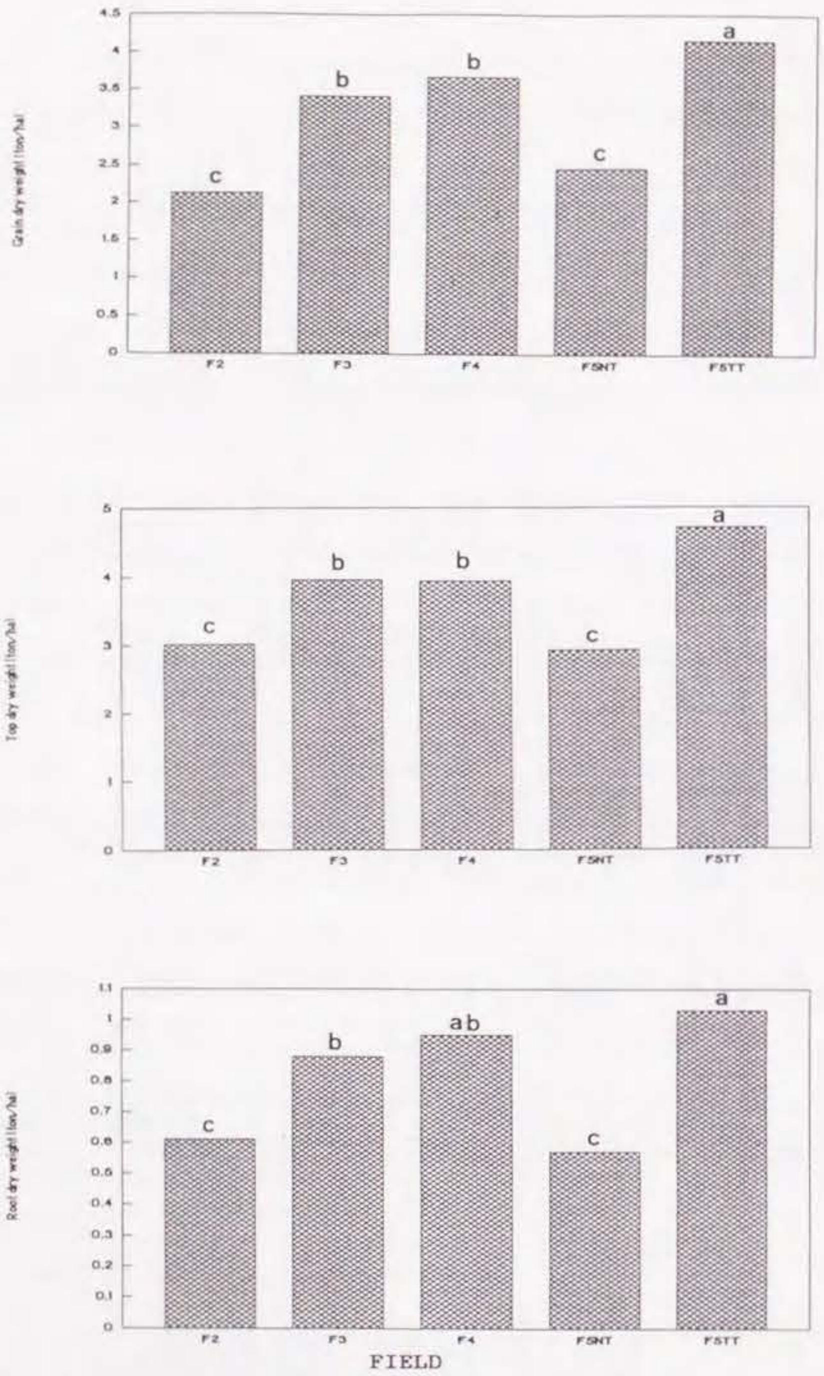


Fig.5-2 Grain yield and dry matter content of maize in F2, F3, F4 and F5

Different letters in a figure for the comparison among different land use history show significant difference at p=0.05

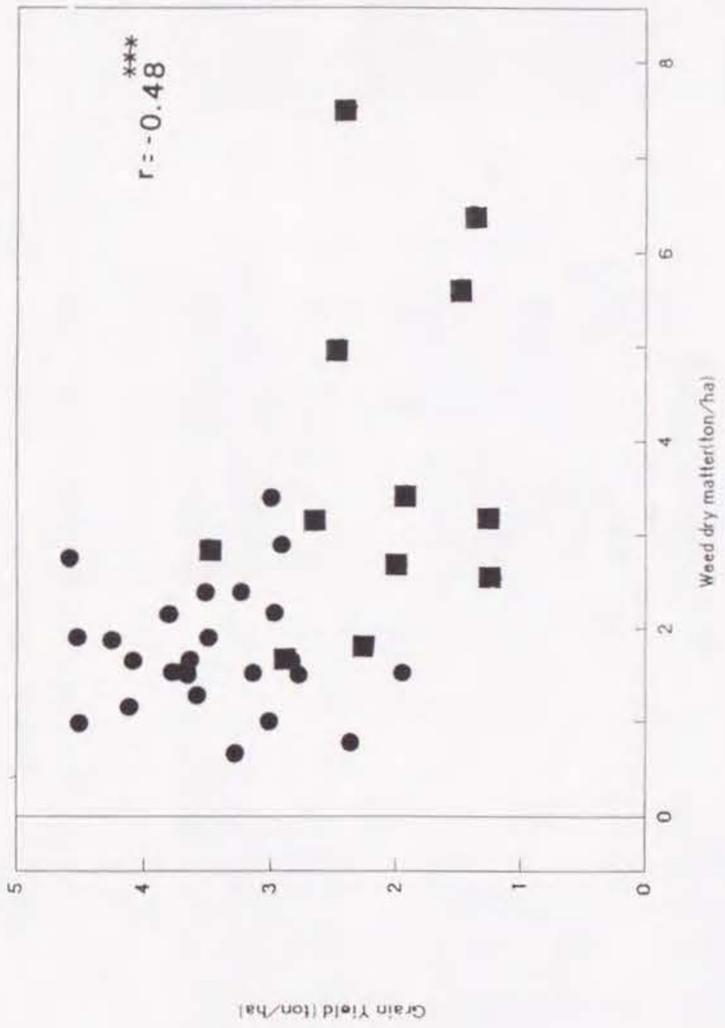


Fig.5-3 Relationship between weed dry matter and grain yield of maize

■ F2, ● F3, F4, F5

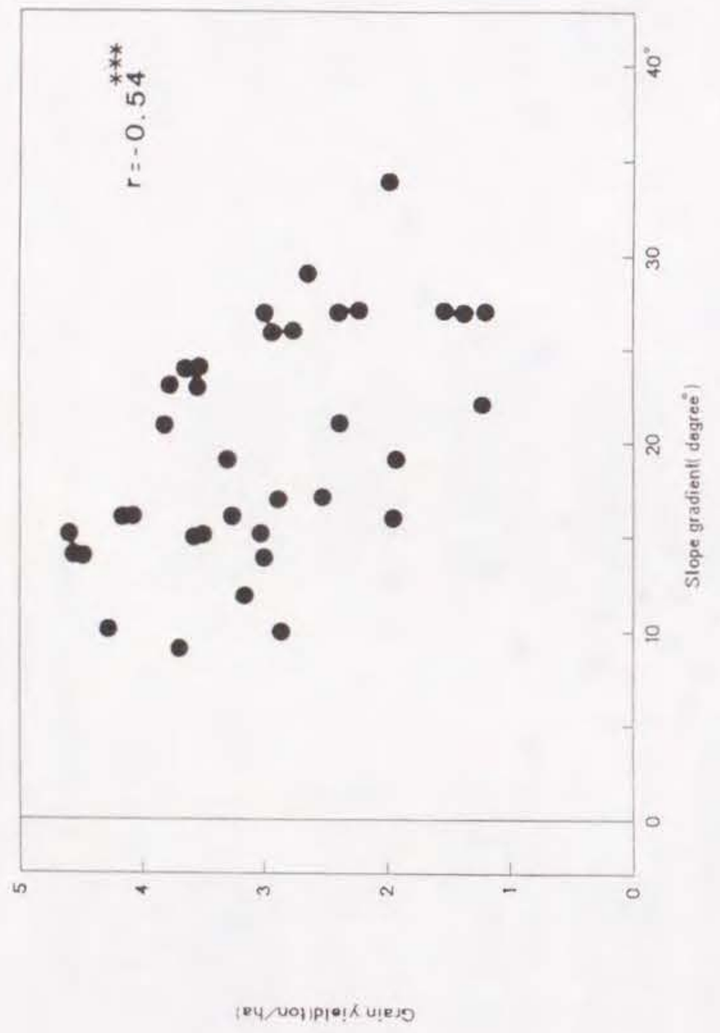


Fig.5-4 Relationship between slope gradient and grain yield of maize

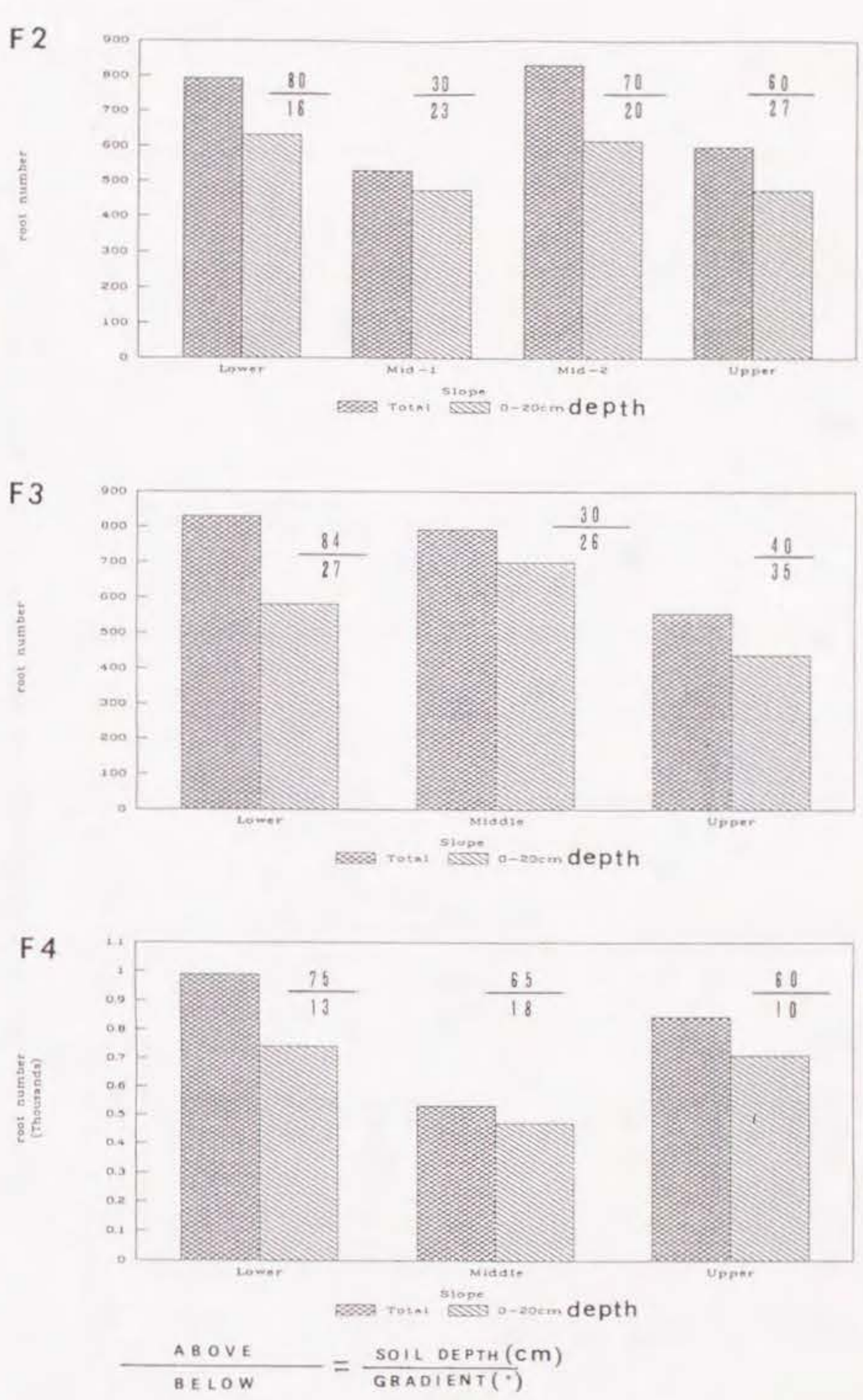


Fig.5-5 Root number of maize in each location of F2, F3 and F4

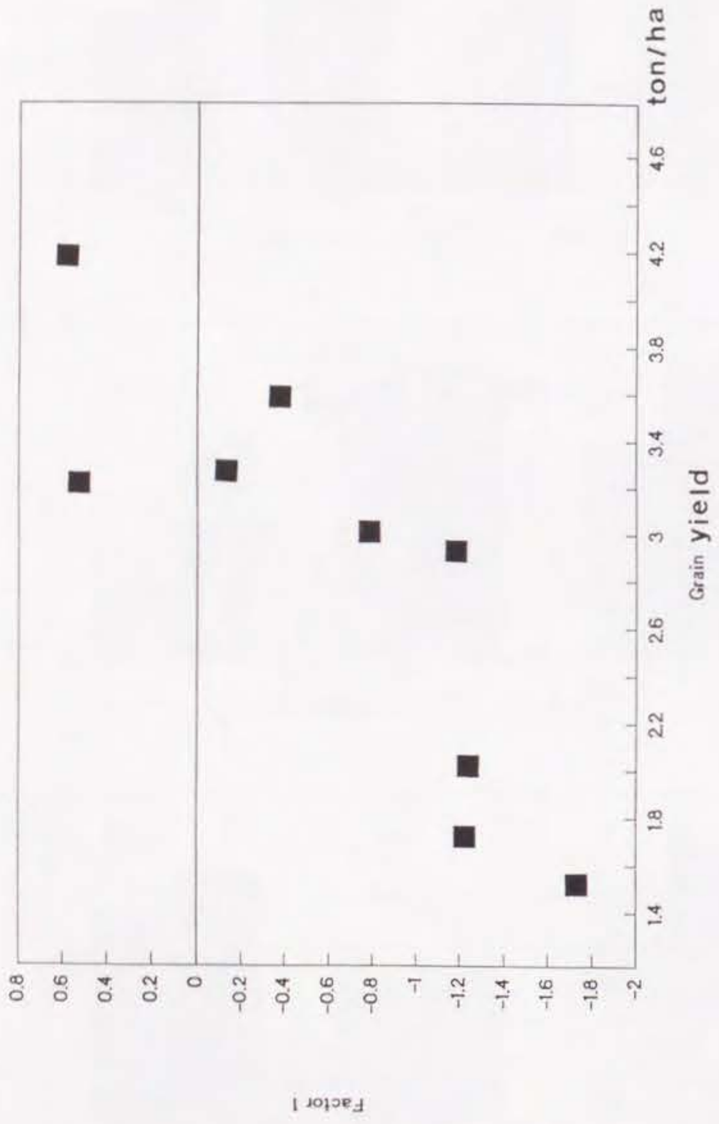


Fig.5-6 Relationship between Factor 1 at 20-30cm depth and grain yield of maize

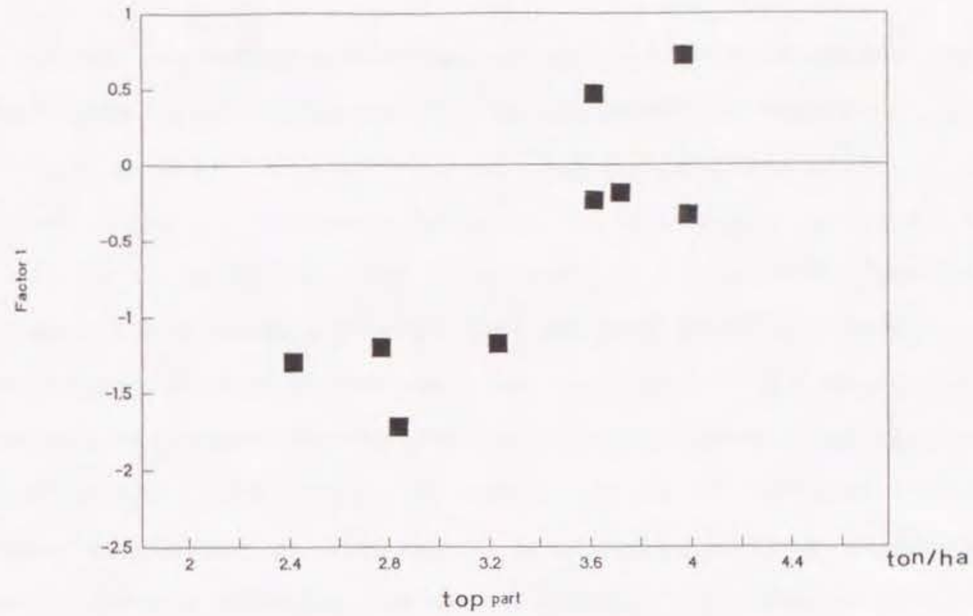


Fig.5-7 Relationship between Factor 1 at 20-30cm depth and the top dry matter of maize

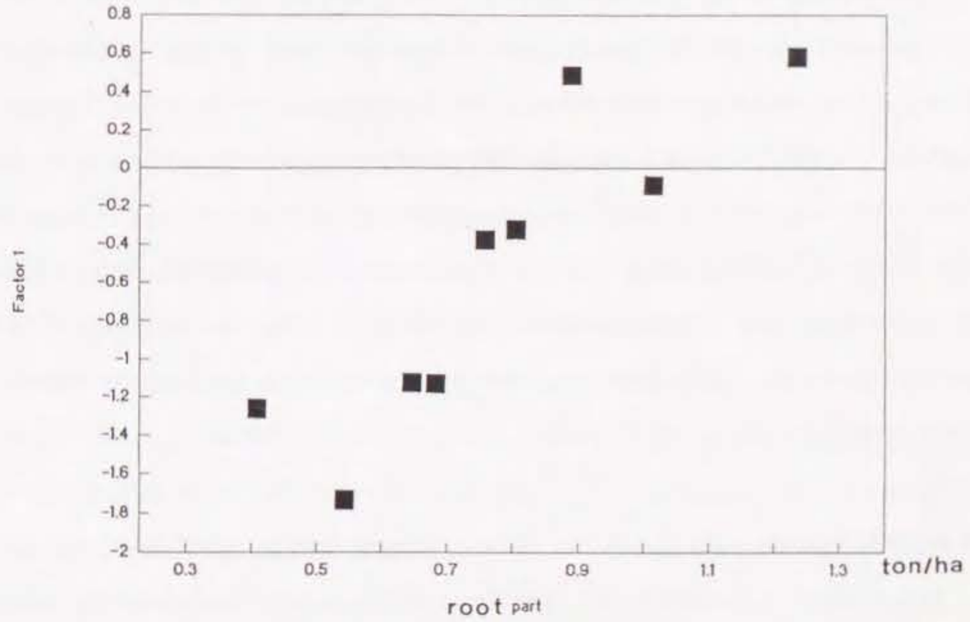


Fig.5-8 Relationship between Factor 1 at 20-30cm depth and the root dry matter of maize

ii) Effect of single-cropping and intercropping on the agronomic characters of maize, upland rice and soybean with tillage

a) Leaf color

Table 5.2 shows data on leaf color of maize and upland rice measured by chlorophyll meter. As far as leaf color of maize under single-cropping in F6 is concerned, while the effect of tractor tillage on maize leaves is negligible, the effect of burning on them is significant. This fact suggests that ash from burning improves soil fertility with a positive effect on maize crop, through ameliorating soil pH and supplying inorganic substances, such as potassium, phosphorus, calcium and magnesium. Leaf color of upland rice also was not significant between the tillage treatments, suggesting a small effect of tillage.

The effect of cropping practices on leaf color of maize and upland rice were significant, that is, in both no-tillage and tractor tillage leaf color of maize and upland rice under intercropping conditions showed significantly higher value than that under single-cropping conditions. These facts may indicate that crops under intercropping conditions enjoy the benefits of solar radiation and the uptake of nutrients or water from soil more effectively.

b) Plant height, dry matter content and grain yields

Mean plant heights of maize and upland rice under single-cropping conditions in F6 are shown in Fig.5-9. The tractor

tillage plots gave larger plant heights of maize than no-tillage plots in any part of slope, and no-burning plots with no-tillage gave the lowest. The effect of the tillage on maize growth appears clearly. Contrary to this, in the lower part of slope tractor tillage plots gave larger plant height of upland rice than no-tillage plots, whereas in the upper part no-tillage plots gave larger. This may be associated with soil depth distribution and the root spread of upland rice. The details will be described later.

Table 5.3 shows grain yields and dry matter content of maize, upland rice and soybean. Data on the seed yields of soybean was excluded from Table 5.3, because many seeds had been eaten by rats before harvesting.

Based on Table 5.3, the following statements may be made.

Maize: The effect of tillage practice , as well as burning, on growth and grain yields of maize under single-cropping conditions is significant. It seems that tractor tillage is effective for promoting maize growth by improved weed control and/or improved water penetration to the root zone.

In no-tillage plots, grain yields, dry matter content of maize intercropped with upland rice and soybean were greater than that of maize single-cropped. On the other hand, in tractor tillage plots, grain yields, dry matter content of maize intercropped with soybean was greater than that of single-cropped plots, whereas maize yields intercropped with upland rice were much the same as that of single-cropping plots, as shown in Fig.5-10.

These facts suggest that growth and grain yields of maize increases when maize is intercropped with soybean or upland rice, in particular, the effect of intercropping appears even stronger under no-tillage conditions.

Upland rice: The effect of intercropping with soybean on grain yields of upland rice appeared clearly as shown in Fig.5-11. However, the effect of tillage practice on grain yield was not significant, whereas the effect on the shoot dry matter in both was significant single-cropping and maize intercropping treatments.

These facts suggest that the intercropping systems with soybean is effective for increasing the grain yields, whereas the intercropping with maize is not necessarily effective. On the other hand, tractor tillage is effective for promoting the growth of upland rice, but not for increasing rice grain yields.

Soybean: Dry matter content of soybean shoots did not show any difference between no-tillage and tractor tillage treatments. In contrast, the root dry matter in tractor tillage plots was much larger than that in no-tillage of all cropping systems as in Table 5.3. In both no-tillage and tractor tillage plots, the dry matter content of soybean roots under single-cropping conditions was the largest in all, and the roots intercropped with upland rice was the smallest, as shown in Fig.5-12.

It seems that tractor tillage is effective for promoting the root growth of soybean, as is a soybean single-cropping system, although it does not improved root distribution, as described later.

Table 5.2 Comparison of Leaf color of maize and upland rice under different cropping system conditions

Treatment	Maize leaf color(SPAD)*)		
	Cropping systems		
	Single-cropping	Intercropping with upland rice	Intercropping with soybean
NT1)	50.1a B	52.4a A	54.1a A
TT2)	49.5a B	57.2a A	59.8a A
NBNT3)	43.0b		
	Upland rice leaf color(SPAD)		
	Single-cropping	Intercropping with maize	Intercropping with soybean
NT	31.9a B	35.2a A	37.4a A
TT	33.0a B	37.3a A	38.7a A

1)NT;no-tillage 2)TT;tractor tillage 3)NBNT;no-tillage with no-burning Different letters(a or b) within a column for the comparison among tillage treatments and(A or B) within a row for the comparison among cropping systems show significant difference at p=0.05, respectively. *;

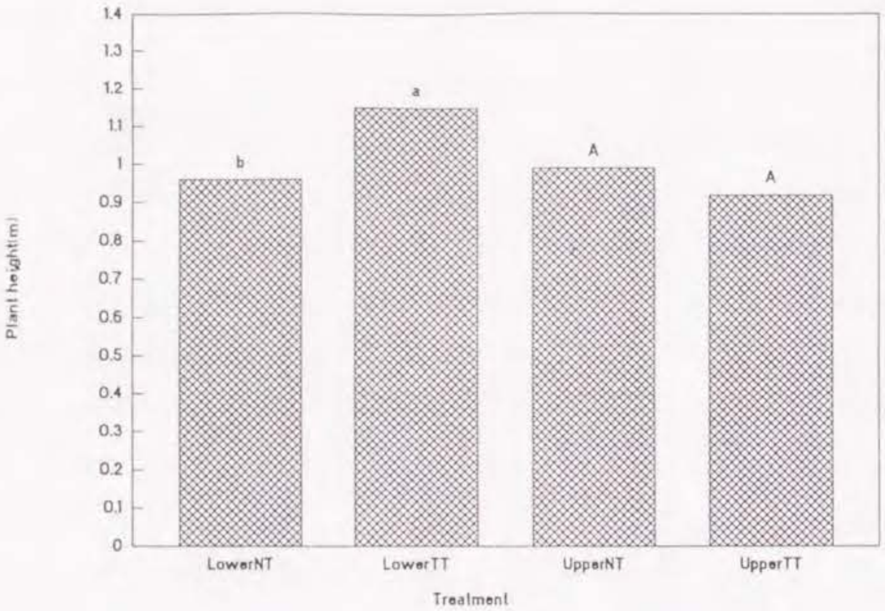


Fig.5-9b Plant height of upland rice under different tillage practices

NT: No-tillage
TT: Tractor tillage
NBNT: No-tillage & No-burning

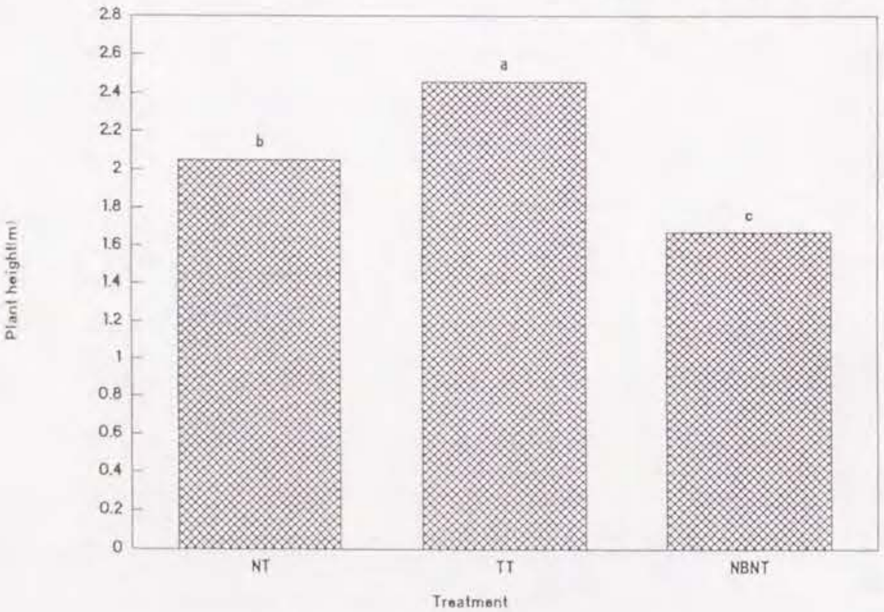


Fig.5-9a Plant height of maize under different tillage practices

Different letters in a figure for the comparison among different tillage practice show significant difference at p=0.05

NT: No-tillage
TT: Tractor tillage

M:maize single-cropping
MR:maize intercropped with upland rice
MS:maize intercropped with soybean

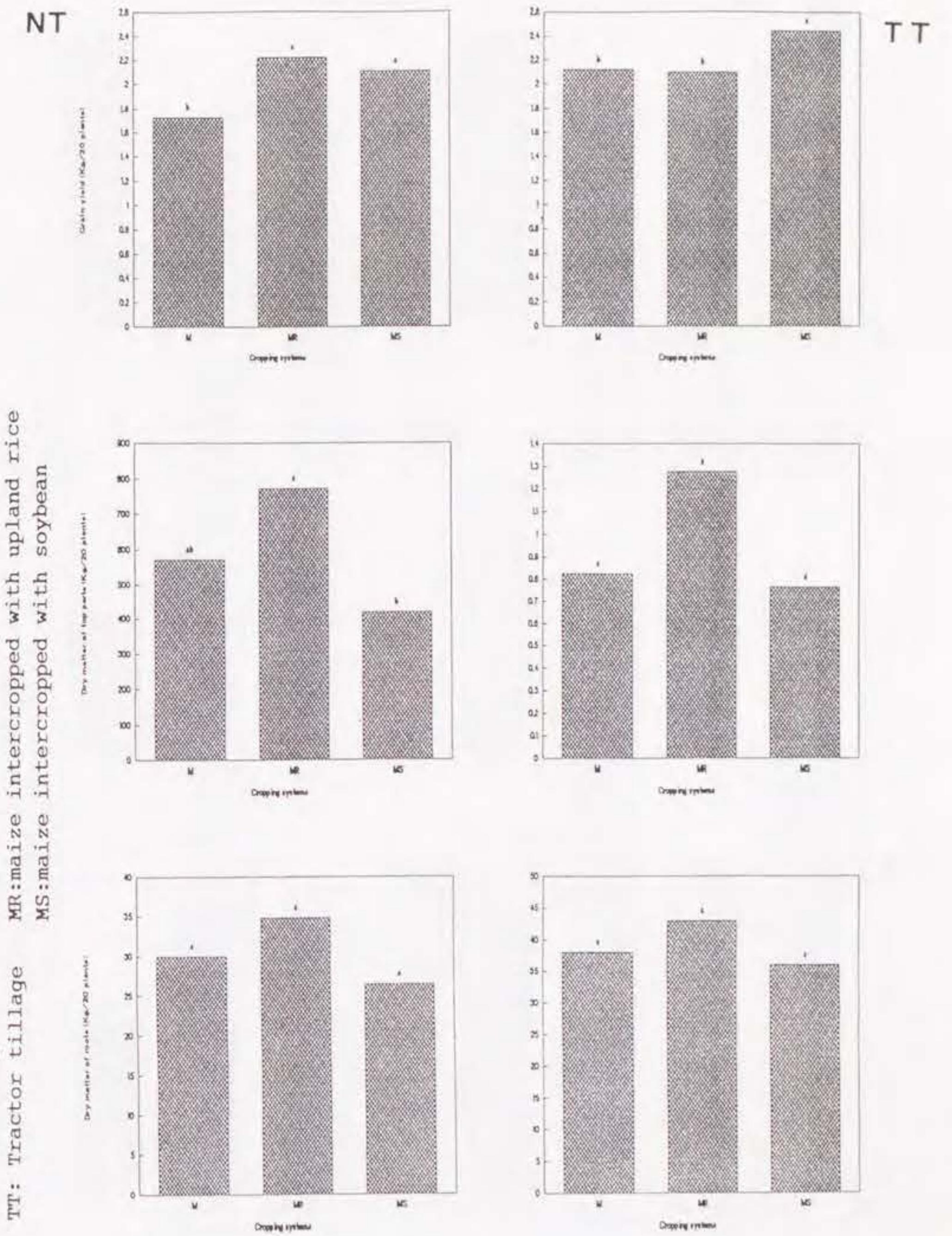


Fig.5-10 Grain yield and dry matter content of maize among different cropping systems under different tillage conditions

Different letters in a figure for the comparison among different cropping systems show significant difference at p=0.05

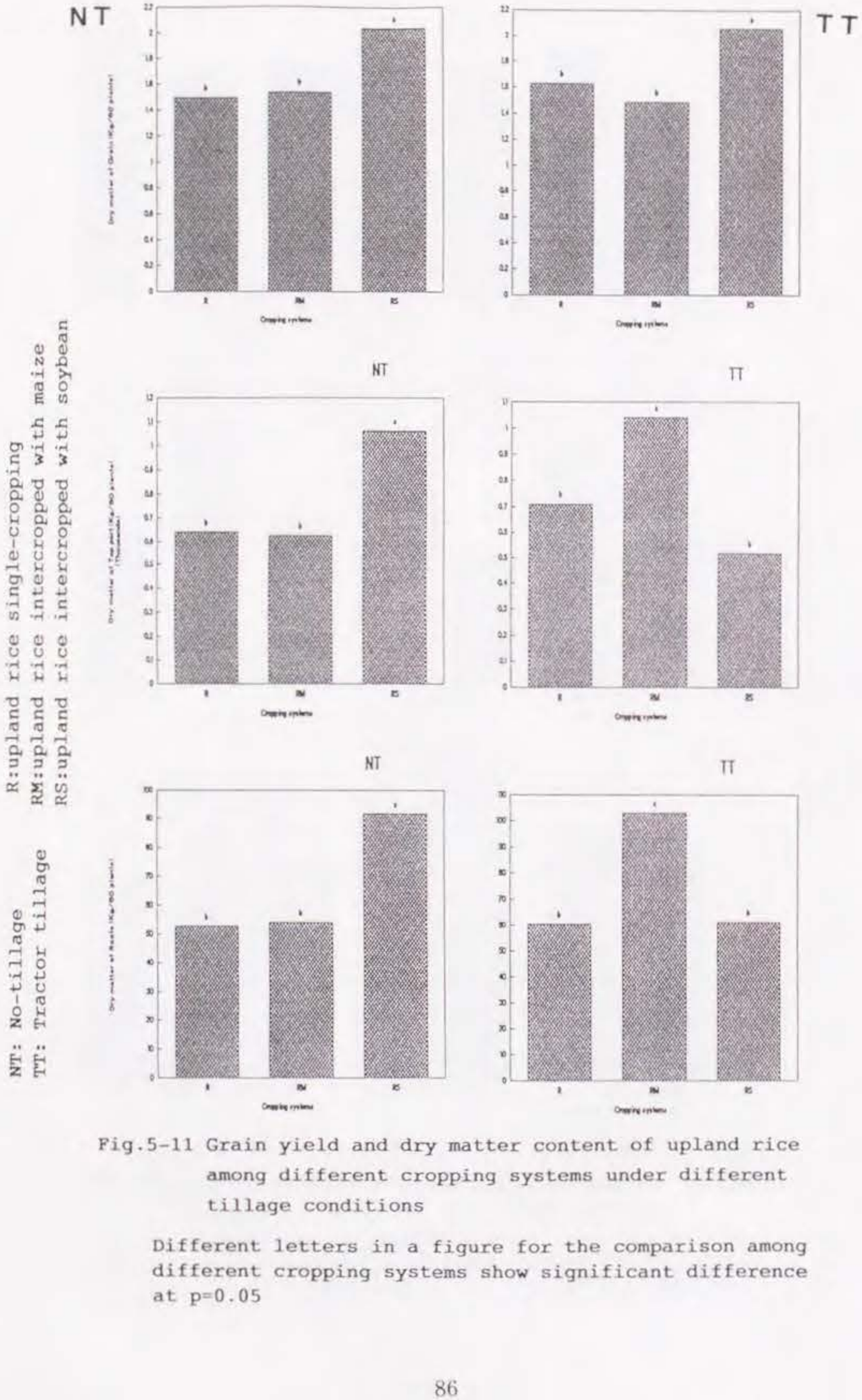


Fig.5-11 Grain yield and dry matter content of upland rice among different cropping systems under different tillage conditions

Different letters in a figure for the comparison among different cropping systems show significant difference at p=0.05

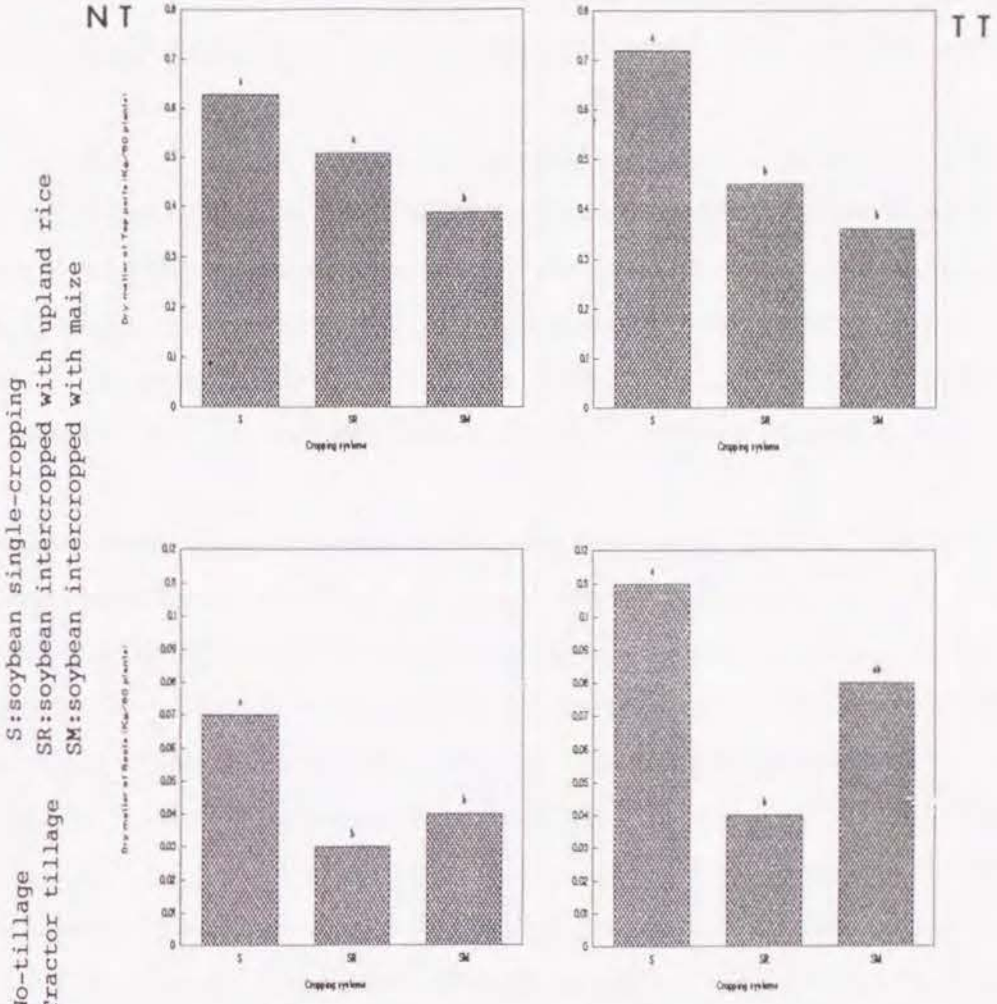


Fig.5-12 Dry matter content of soybean among different cropping systems under different tillage conditions

Different letters in a figure for the comparison among different cropping systems show significant difference at p=0.05

c) **Root length and root number**

Root length of maize, upland rice and soybean was measured after counting all excavated roots, and represented as mean root length, total root length and the number. The results will be described in each crop as follows.

Maize: Data on maize roots are shown in Table 5.4 and Fig.5-13. Under both single-cropping and intercropping conditions, mean root length in tractor tillage plots was larger than that in no-tillage plots. The total root length and root number in tractor tillage plots also were large in comparison with no-tillage plots (Table 5.4).

On the other hand, in both no-tillage and tractor tillage plots, the mean root length of maize intercropped with upland rice was the largest in all cropping systems, while the length between single-cropping and intercropping with soybean did not differ significantly. Also, the total root length and root number when intercropped with upland rice showed a large value in comparison with the others.

This suggests that total root length of maize become longer when the crop is intercropped with rice and/or in tractor tillage plots, although the orientation of roots is obscure. However, if the data are contrasted with the profile observations, better results may be obtained from them.

Upland rice: Data on upland rice roots are shown in Table 5.4 and Fig.5-14. Under both single-cropping and intercropping conditions, the mean root length in no-tillage plots was larger than that in tractor tillage, while the root number and total

root length in single-cropping and intercropped with maize in tractor tillage were large compared with in no-tillage. However, in the case of intercropped with soybean, those in no-tillage plots was larger than in tractor tillage.

In no-tillage plots, the root number and total root length in single-cropping plots were the largest of all, but the mean root length was not difference among the cropping systems. On the other hand, in tractor tillage plots, the mean root length in single-cropping plots was larger than that in the other plots, but the root number and the total length when intercropped with maize were the largest.

These facts suggest that total root length of upland rice become longer when the crop is intercropped with soybean under no-tillage conditions or with maize under tractor tillage conditions.

Soybean: Data on soybean roots are shown in Table 5.4 and Fig.5-15. Under sigle-cropping conditions, the mean root length of soybean in tractor tillage plots was larger than that of no-tillage plots, but the mean root length under intercropping conditions was not significantly different. The total root length and root number of soybeans intercropped with rice in tractor tillage plots was larger than those in no-tillage ones.

In no-tillage plots, the mean root length, the total root length and the root number under single-cropping conditions were larger than those under intercropping conditions. In tractor tillage plots, while the mean root length under single-cropping conditions was large in comparison with that under intercropping conditions, the total root length and the root number were not significantly different among them.

These facts suggest that the mean root length and the total root length become longer when the crop is grown under single-cropping conditions and/or in tractor tillage plots.

Table 5.3 Comparison between grain yield and biomass of maize, upland rice and soybean under no-tillage and tractor tillage conditions with single-cropping and intercropping systems

Treatment	Grain	Top	Root	Whole	T/R
	Maize(Kg/20plants)				
Single-cropping					
NT[1)]	1.73b	1.91b	0.14b	3.78	26.0
TT[2)]	2.12a	2.89a	0.18a	5.19	27.8
NBNT[3)]	1.31c	0.99c	0.07c	2.37	32.9
Intercropping with upland rice					
NT	2.22a	3.93a	0.19b	6.34	32.4
TT	2.10a	3.69a	0.28a	6.07	20.7
Intercropping with soybean					
NT	2.11b	2.50b	0.11a	4.72	41.9
TT	2.45a	3.00a	0.17a	5.62	32.1
	Upland rice(Kg/60plants)				
Single-cropping					
NT	1.50a	1.92b	0.13a	3.55	26.3
TT	1.63a	3.15a	0.15a	4.93	31.9
Intercropping with maize					
NT	1.54a	1.59b	0.09a	3.22	34.8
TT	1.49a	3.21a	0.11a	4.81	42.7
Intercropping with soybean					
NT	2.04a	2.45a	0.08a	4.57	56.1
TT	2.06a	2.98a	0.07a	5.11	72.0
	Soybean(Kg/60plants)			(Top+Root)	
Single-cropping					
NT	*	0.63a	0.07b	0.70	
TT	*	0.72a	0.11a	0.83	
Intercropping with upland rice					
NT	*	0.51a	0.03a	0.54	
TT	*	0.45a	0.04a	0.49	
Intercropping with maize					
NT	*	0.39a	0.04b	0.43	
TT	*	0.36a	0.08a	0.44	

1)NT; no-tillage 2)TT;tractor tillage 3)no-tillage with no-burning
Different letters within a column for the comparison between tillag treatments show significant difference at p=0.05

Table 5.4 Comparison of average root length and root number of maize, rice and soybean under different cropping and tillage conditions

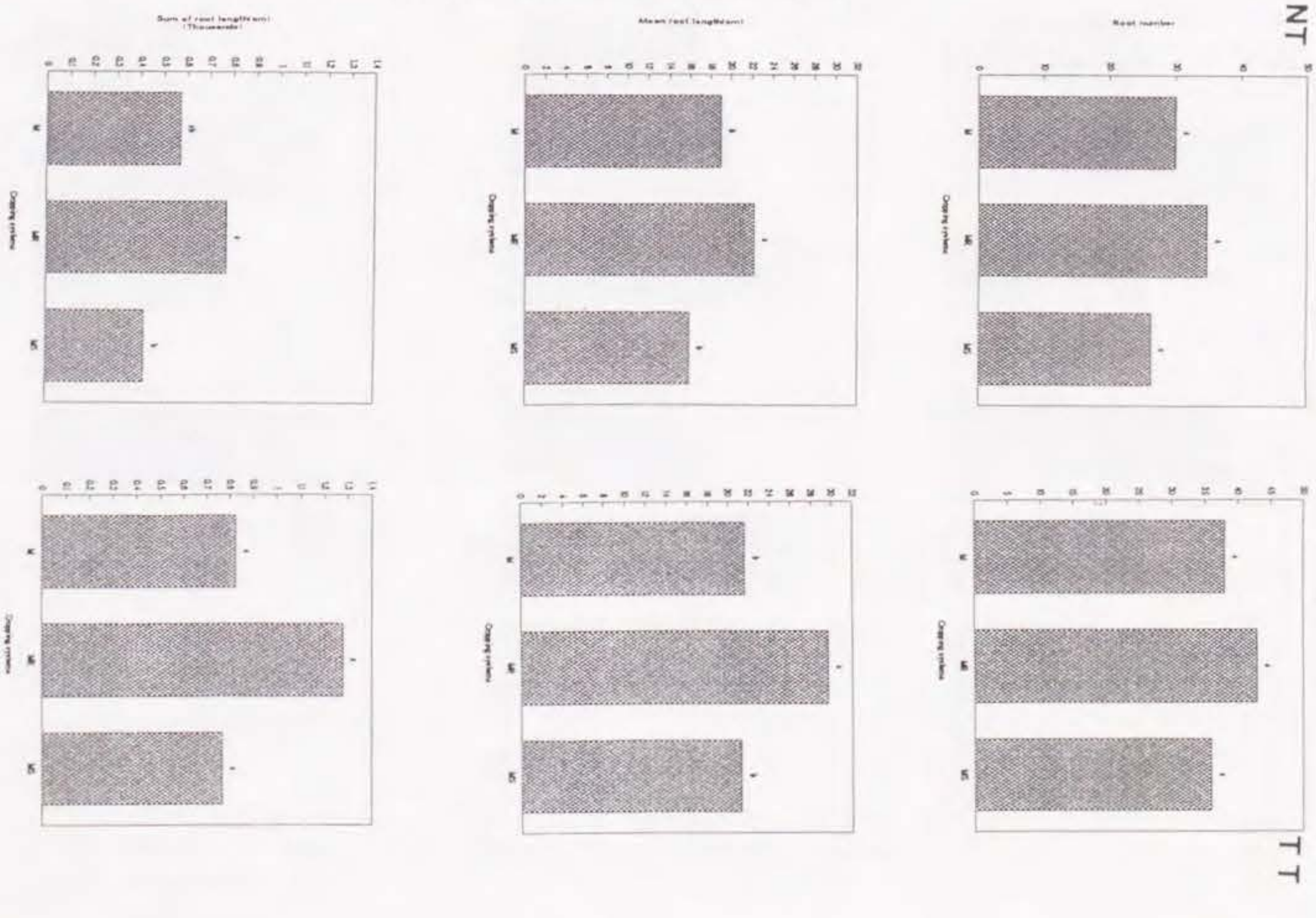
Crop / Cropping	Average root length(cm)		Root number	
	No-till	T-till	No-till	T-till[1)]
Maize				
Single cropping	19.03b	21.65a	30.00a	38.11a
Intercropping				
with rice	22.17b	29.72a	34.83a	43.00a
with soybean	15.84b	21.31a	26.42a	36.00a
Rice				
Single cropping	11.29a	10.11b	52.70a	60.50a
Intercropping				
with maize	11.61a	10.12b	54.00b	102.90a
with soybean	9.28a	8.51b	91.67a	61.00b
Soybean				
(tap root)				
Single cropping	22.65b	41.17a	*	*
Intercropping				
with rice	16.14a	16.15a	*	*
with soybean	12.79a	17.60a	*	*
(secondary root)				
Single cropping	13.79b	19.56a	8.53a	7.21a
Intercropping				
with rice	11.41a	11.25a	5.09b	12.67a
with maize	10.57a	8.55a	4.70a	5.90a

1) No-till; No-tillage, T-till;Tractor tillage
Different letters within a row for the comparison between different tillage practices in each crop show significant difference at p=0.05

NT: No-tillage
TT: Tractor tillage

M:maize single-cropping
MR:maize intercropped with upland rice
MS:maize intercropped with soybean

NT



TT

Fig.5-13 Mean root length, total root length and root number of maize among different cropping systems under different tillage conditions
Different letters in a figure for the comparison among different cropping systems show significant difference at p=0.05

NT: No-tillage
TT: Tractor tillage

R:upland rice single-cropping
RM:upland rice intercropped with maize
RS:upland rice intercropped with soybean

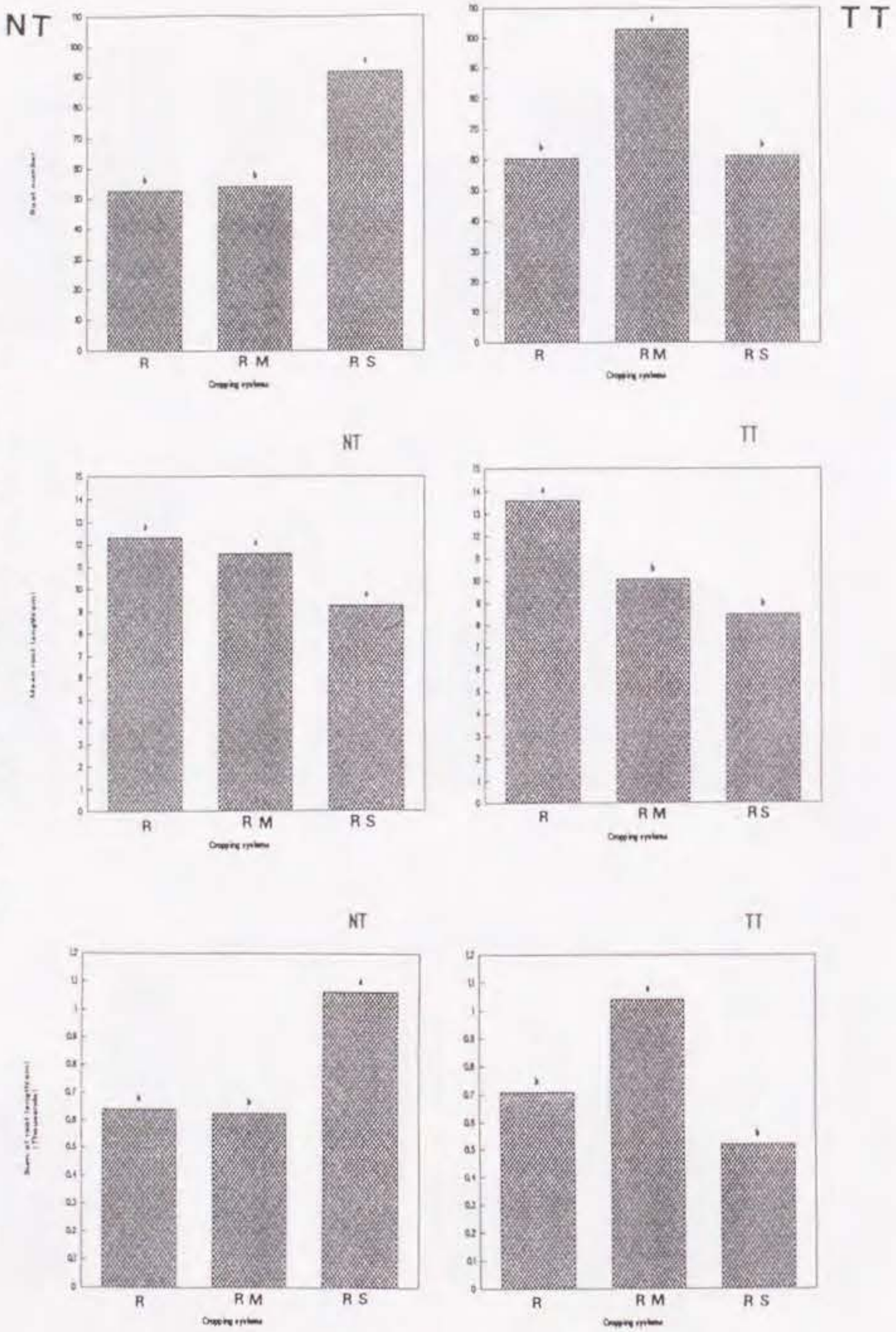


Fig.5-14 Mean root length, total root length and root number of upland rice among different cropping systems under different tillage conditions

Different letters in a figure for the comparison among different cropping systems show significant difference at p=0.05

NT: No-tillage
TT: Tractor tillage

S:soybean single-cropping
SR:soybean intercropped with upland rice
SM:soybean intercropped with maize

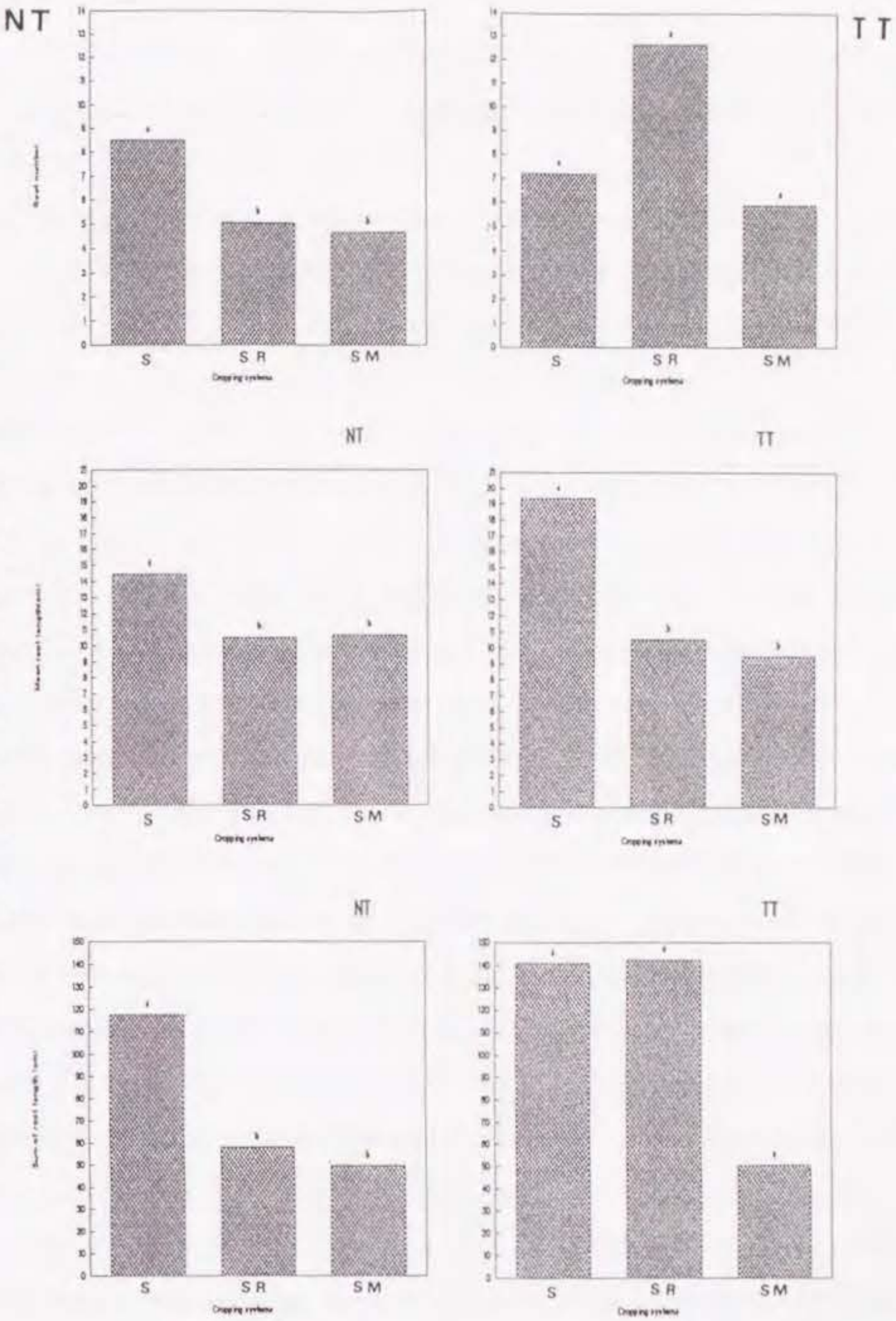


Fig.5-15 Mean root length, total root length and root number of soybean among different cropping systems under different tillage conditions

Different letters in a figure for the comparison among different cropping systems show significant difference at p=0.05

CHAPTER 6 Characteristics of root distribution

6.1 Distribution of maize and soybean root systems under single-cropping and intercropping conditions in experimental field in Japan

Intercropping is one of the traditional agricultural practices in the tropics. It is generally recognized that the intercropping system offers many advantages both from the temporal and spatial aspects only with the combination of crops with different physiological characteristics and differences in the cultivation period or plant types. One of the mechanisms may be related to the fact that interspecific competition for light, water and nutrients is minimized.

Most of the studies on competition under intercropping systems have been conducted to evaluate the effect of photosynthesis in terms of competition of above ground plant parts. However, much less is known about the relationships of the parts below the ground, although it is generally agreed that competition for water and nutrients is more frequent and severe than competition for light.

Above all, limited information is available about root development when two or more crops are grown simultaneously. Roots also play important roles in crop productivity, even if the effect is indirect. The root system, however, cannot be easily studied. due to the complexity of its pattern and wide

distribution. Moreover, in the field, roots cannot be observed directly in soil. Therefore, few publications relating to this kind of research are available.

In this section, distribution of the root system of maize and soybean was analyzed under intercropping conditions to be compared with that under single-cropping conditions in Japan, preceding the study in slash burn field in Thailand.

6.1.1 Materials and methods

1. Maize (*Zea mays* L.) and soybean (*Glycine max* Merr.) were used in this experiment. The seeds of 'Skyliner 95' a medium-maturing sweet corn variety, were sown on June 17. The seeds of 'Tamanishiki' a late-maturing soybean variety, were sown on June 23. These crops were planted at an interhill spacing of 15 cm and 30 cm in each plot, under both single-cropping and intercropping conditions. Leaf area per plant and dry matter yield of the whole plant, root and grain were recorded as agronomic characters. At maturity the whole plants were removed, and their root systems were investigated. This experiment was carried out by using a modified soil monolith under field conditions in the field of the Experimental Farm of Kyoto University during the period of June - October, 1988 and 1989. The soil was a kind of brown lowland soil, and the site had been cultivated with potato and sweet potato during the previous two years. The experiment was carried out under no-tillage, no-fertilization and rain-fed conditions.

Each experimental plot was set up as follows: maize single-cropping (A-plot), soybean single-cropping (B-plot), intercropping with maize planted between soybean plants (C-plot) and intercropping with soybean planted between maize plants (D-plot) as shown in Fig.6-1. Five replications were prepared for the root investigations and three replications for the determination of the agronomic characters in each case.

2. A series of field experiments was conducted to disclose differences in the characteristics of the rooting systems between single-cropping and intercropping of row crops. A modified soil monolith with a needleboard was used for the visual characterization of the root pattern of maize and soybean under different cropping systems. A first trench was dug parallel to the central line in a row. Plywood board (90 x 90 cm) was placed against the trench wall, vertically. Glass poles (4.5mm diameter) were driven 30 cm into the soil through holes drilled in the board at the intersection of 5.0 cm square grid, to a 75 cm length. A second trench was dug on the opposite side of the central line, parallel to and 30 cm from the initial trench.

The board holding roots was lifted out after removal of soil by hand, and was soaked into trisodium metaphosphate as dispersion solution for 24 to 48 hours. Thereafter, a fine water spray was used to remove all the soil materials gently, leaving the intact roots in their relative position by using glass poles.

After the root systems were washed out completely, they were photographed without removing it from the board. To keep the roots as much as possible in their natural position the board was sprayed with a dilute water-soluble adhesive agent to solidify

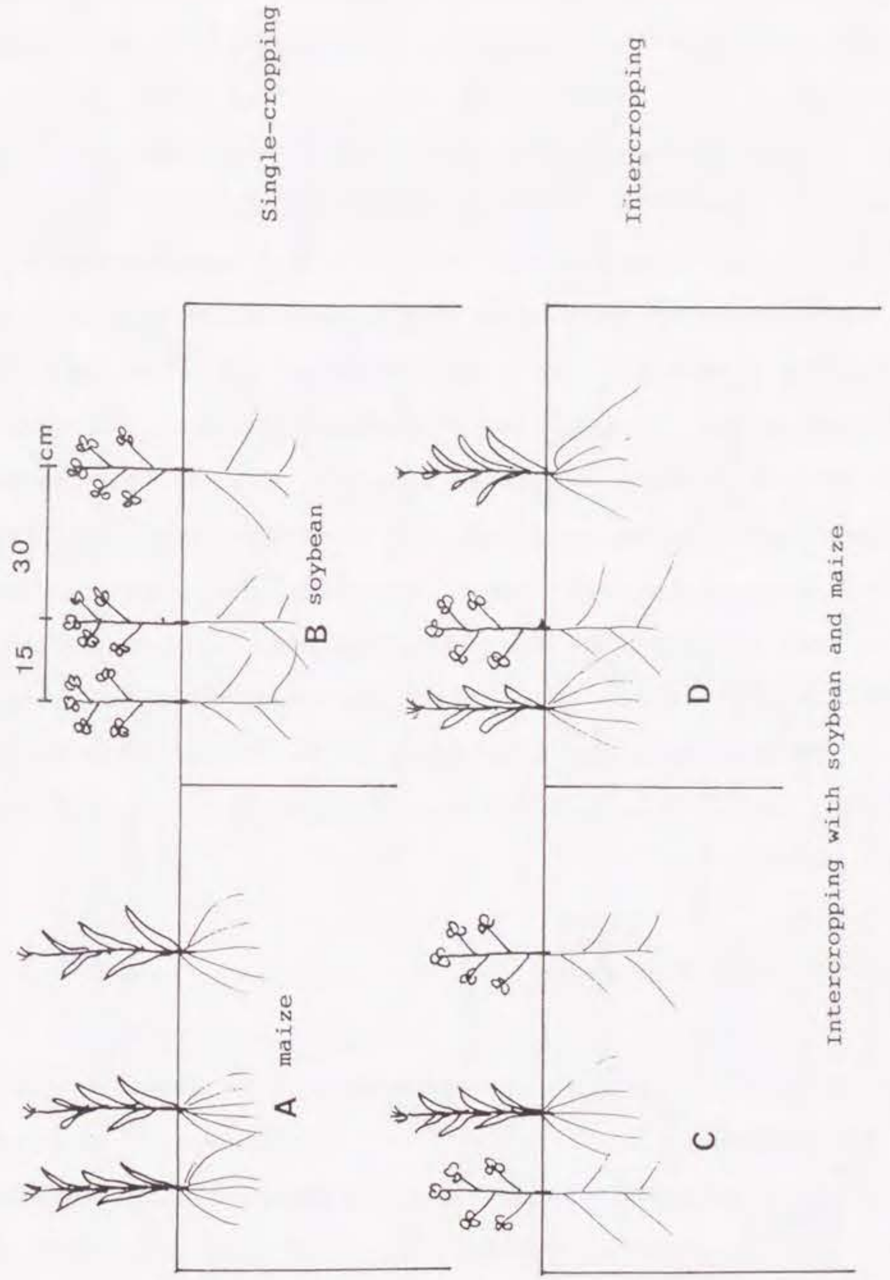


Fig.6-1 Experimental plots of single-cropping and intercropping

the roots. This method is original.

3. Drawing of root systems. The glass pole was taken off from the board after fixing the roots on the board. A translucent polyethylene sheet was stretched over the root system, and the outline was traced on the sheet using color felt pens, to the second or third branch for every root. Thereafter, another translucent sheet which was marked with a 3 x 3 cm grid net was put on the sheet with the root face. The number of crossing roots in the square grid was counted, and recorded in 5 mm section paper, referred to as "root number distribution chart". A chart of the root system pattern was drawn by using it. In this study the root number is represented by the average value of five replications. This chart was used to measured the area of root distribution and competition. However, the root system was not investigated from all angles, but from a vertical direction only. All the results were statistically analyzed by Duncan's multiple range test or general linear model to estimate the significance of different means.

6.1.3 Results and discussion

i) Effect of intercropping on the agronomic characters of maize and soybean

Leaf area per plant: When maize was intercropped with soybean in the C and D plots shown in Fig.6-1, the leaf area per plant of maize and soybean was greater at 10 weeks after sowing in comparison with the values when each of the crop was planted in

Table 6.1 Comparison between single cropping and intercropping on the leaf area per plant(cm2) and dry matter yield(g/plant) of maize and soybean at the different stages

		L.A/plant		D M Y			
				Whole		Grain	Root
		Weeks after sowing		Weeks after sowing			
Crop	Treatment	5W	10W	5W	10W	At harvest	
Maize							
	Single cropping	1140.8a	2301.8b	5.21a	61.55a	33.98b	15.22b
	Intercropping	1012.5a	2895.8a	4.77a	76.06a	39.02a	19.82a
Soybean							
	Single cropping	1552.5a	6027.8b	10.43a	46.86a	39.51a	24.34a
	Intercropping	1640.3a	7526.3a	11.22a	55.76a	40.34a	23.15a

Abbreviation: L. A/plant , leaf area per plant; D M Y, Dry matter yield
This data are the average of 4 samples for L.A/plant, D M Y of root, and of 10 samples for grain.
Different letters within a column for the comparison between two treatments in each crop show significant difference at p=0.05

pure stand, as in the case of A and B plots shown in Fig.6-1 and Table 6-1.

Dry matter content of maize and soybean: Dry matter content of the whole plant in both maize and soybean was not significantly different between single-cropping and intercropping at 5 weeks and 10 weeks after sowing. At harvest, however, the grain yield and root dry matter content of maize under intercropping conditions increased in comparison with single-cropping. On the other hand, grain yields as dry matter content of soybean under intercropping conditions were not significantly different from the values under single-cropping (Table 6.1).

As a result, it is considered that maize intercropping with soybean resulted in a significant increase in the dry matter content of grain and root. It is assumed that the effect of solar radiation on intercropped maize was more significant than an intercropped soybean, as evidenced by the increase in the leaf area per plant at 10 weeks after sowing, or possible effect of N-fixed by soybeans?

ii) Root distribution pattern under single-cropping conditions

Maize: The root distribution pattern in this study was represented by the extent of roots in the grids of the "root distribution chart". Fig.6-2a shows that the extent of the root distribution of maize under single-cropping in the A-plot was restricted with depth. The root distribution type of each crop in the plot showed differences depending on the spacing. The roots of the plants of a 15 cm interhill spacing (close planting)

extended to the upper and middle layers in the profile. The roots of the plants of a 30 cm interhill spacing (wide planting) markedly extended to the middle. The extent of the root distribution in the widely spaced planting was larger than that in close planting, in particular, in the middle of the profile. Consequently the root distribution in the case of widely spaced planting showed an 'oval type', whereas in close planting it showed a 'streamline type'.

Soybean: Fig.6-2b shows that the extent of the root distribution of soybean under single-cropping in the B-plot also tended to be restricted with depth. The roots were located within the upper 30 cm zone in the soil profile. The root distribution of each planting density showed a similar tendency to that of maize under single-cropping, though the zone of root extension was slightly different. The root distribution in wide planting in the upper part of the profile extended more laterally than that in the middle and/or the bottom, showing an 'oval type in contrast to the 'streamline type' in close planting.

iii) Characteristics of root distribution under intercropping systems

The root system of maize and soybean showed differences between intercropping and single-cropping conditions. Fig.6-2c indicates that the root distribution of maize planted between soybean plants in the C-plot extended over the neighboring root system of soybean in the middle part in the profile, as if there were no adjacent plants. The root distribution of soybean

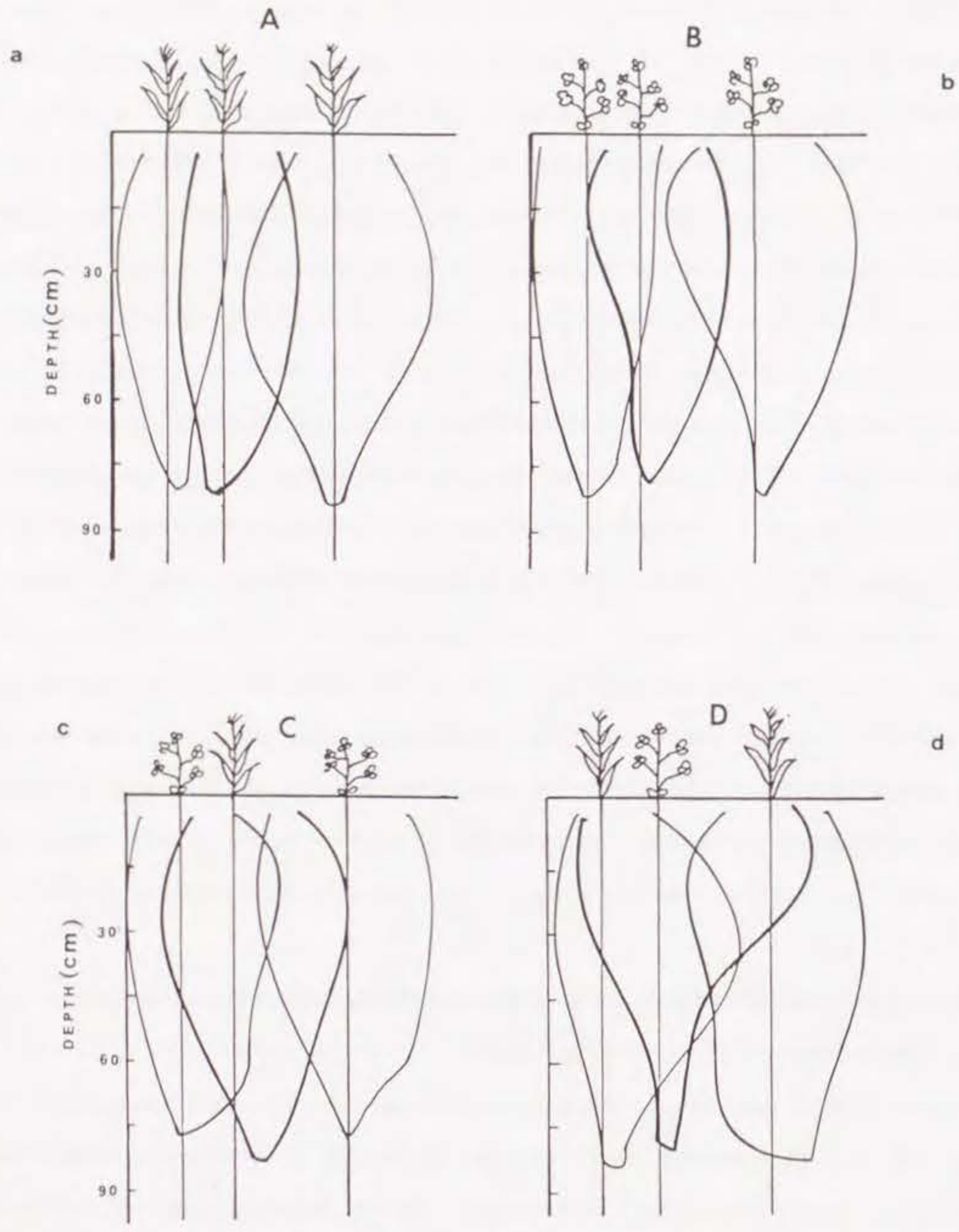


Fig.6-2 Root distribution under single-cropping and intercropping with maize and soybean

intercropped with maize also showed a similar pattern, though the roots extended over the adjacent maize roots both in the upper and middle parts of the profile. Although the tendency was observed both in close and wide plantings, the extent of root distribution in close planting was larger than that in wide planting.

Fig.6-2d shows that the root distribution of soybean planted between maize plants in the D-plot extended over the neighboring root system of maize in the upper part of the profile. The root distribution of maize intercropped with soybean also showed a similar tendency, and the roots extended over a larger area in the middle layer of the profile in close planting when compared to wide planting.

As a result, it is concluded that the root distribution of maize or soybean under intercropping overlapped with that of the counterpart crop.

iv) Comparison of characteristics of root distribution between different cropping systems

There are marked differences in the root distribution between single-cropping and intercropping systems as shown in Fig.6-3 and Fig.6-4. The root distribution of maize grown under single cropping conditions as shown in the A-plot was compared with that under intercropping conditions as shown in the C-plot. The extent of the lateral distribution of maize roots in the C-plot was much larger than that in the A-plot. The pattern of the extent of root distribution of maize in the A-plot was markedly different from that in the D-plot. The area of root distribution overlapping with that of other plants in the C-plot was significantly larger than that of A-plot, as indicated by the shaded portion in Fig.6-3 and in Table 6.2.

Fig.6-3 shows that the extent of maize root distribution under intercropping conditions was much wider horizontally compared with single-cropping. The area of root elongation under different cropping conditions is indicated in Table 6.2 which shows that the root system area of maize, when the interhill spacing was narrow, was larger under intercropping conditions than under single-cropping. Also, the area of the root system of maize which overlapped with the root system of neighboring plants, when the hill position was in the center of the row, was significantly larger under intercropping conditions than under single-cropping, as represented by the competition area of the central crop in Table6.2. On the other hand, when the interhill spacing was wide, the root system area of maize was not significantly different between the two cropping systems.

Table 6.3 shows a comparison of the vertical and lateral distribution of the number of maize roots between single-cropping and intercropping. Although the number of maize roots was not different in the center of the rooting zone, it was significantly different in the area away from the center. These findings indicate that under intercropping conditions the root system area of maize was extended as the root number also increased.

The root distribution of soybean in the B-plot where soybean was single-cropped was compared with that in the D-plot where

Table 6.2 Comparison of root system area(cm^2) and competition area rate between single cropping and intercropping with maize and soybean

Crop Treatment	Root system area			Competition area rate in center crop(%)	
	Hill position in row				
	Left	Center	Right[1)]	L in C	R in C[2)]
Maize					
Single cropping	1404.0b	1591.2b	1989.0a	27.5b	16.1b
Intercropping	1924.2a	2305.8a	2192.4a	50.9a	31.3a
Soybean					
Single cropping	1393.2b	1871.2a	1994.4a	22.4b	21.9b
Intercropping	1798.2a	1877.4a	1981.8a	51.6a	35.0a

1)Left, narrow interhill space(15cm); Right, wide interhill space(30cm); Center, narrow at left side and wide at right.
2)L in C and R in C; area of left crop root and of right one in center crop root area.
Different letters within a column for the comparison between two treatments in each crop show significant difference at p=0.05

Table 6.3 Comparison of vertical and lateral distribution of root number between single cropping and intercropping with maize and soybean

crop	Depth from the ground (cm)	Single cropping 0-30	Single cropping 30-60	Intercropping 0-30	Intercropping 30-60
Maize	0-15	74.0a	5.8A	74.5a	8.8A
	15-30	64.6a	3.2B	79.0a	22.5A
	30-45	49.8a	1.6B	46.3a	14.5A
	45-60	21.8a	1.8B	23.8a	11.8A
	60-70	8.4a	1.0A	6.8a	6.5A
	Total	218.6a	13.4B	230.4a	64.1A
Soybean					
	0-15	82.4a	8.2A	77.8a	17.5A
	15-30	44.0a	6.8B	42.0a	20.8A
	30-45	21.8a	4.0B	28.5a	11.5A
	45-60	13.2a	0.2B	11.8a	11.3A
	60-75	6.6a	0.8A	1.8a	4.0A
	Total	168.0a	20.0B	161.9a	65.1A

Distance from center hill(cm)

Different letters within a line for the comparison between two cropping methods show significant difference at p=0.05

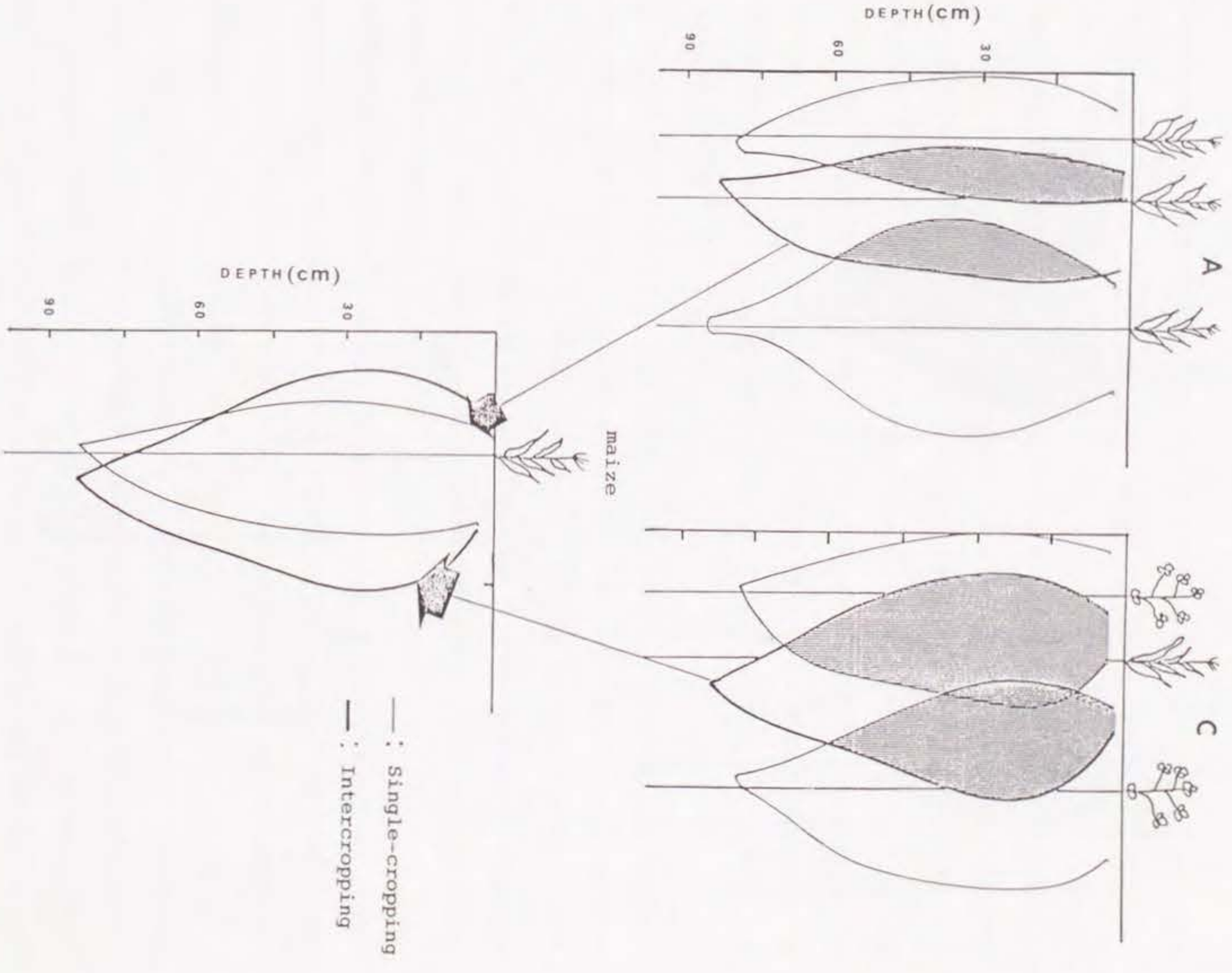


Fig.6-3 Comparison of the root distribution of maize between single-cropping and intercropping with soybean

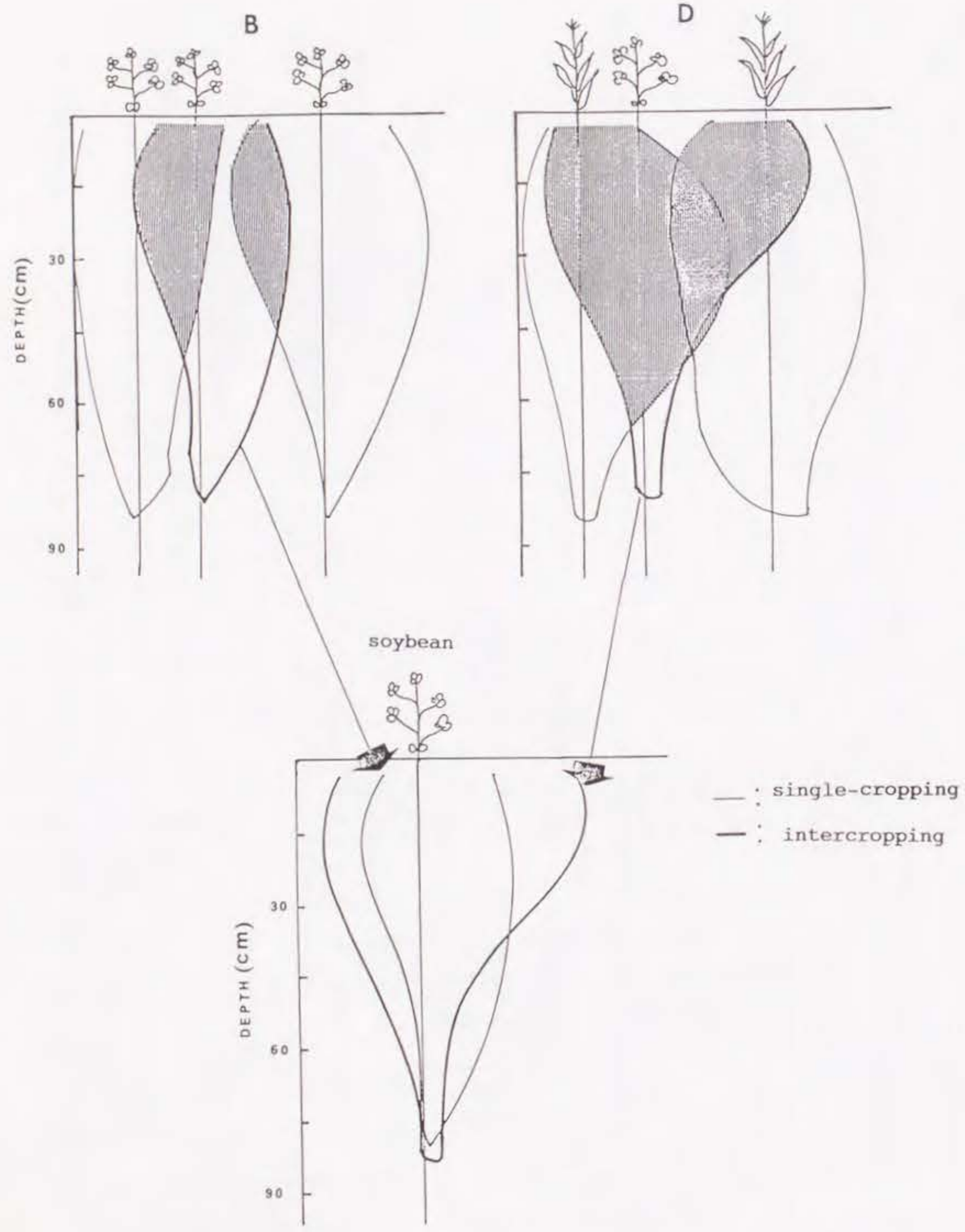


Fig.6-4 Comparison of the root distribution of soybean between single-cropping and intercropping with maize

soybean was intercropped with maize. The lateral extent of soybean roots in the D-plot was larger than that of the B-plot. Differences in the pattern of the distribution of soybean roots between the B-plot and D-plot were conspicuous. The lateral distribution of the soybean roots in the D-plot extended markedly into the neighboring root system area, from the upper to the middle layers in the profile, unlike in the B-plot. Thus, the overlapping area of the root system of soybean with that of maize under intercropping was significantly larger than that under single-cropping, as indicated by the shaded portion in Fig.6-4 and in Table 6.2.

Table 6.2 shows that the root system area of soybean intercropped with maize for the narrow interhill spacing was larger than that of soybean under single cropping. The root system area overlapping in the central crop under intercropping conditions was significantly larger than that under single-cropping.

The vertical and lateral distributions of the number of roots in soybean and maize under different cropping systems are shown in Table 6.3. The distribution of the root number in soybean was similar to that in maize.

On the basis of these figures, it is considered that the root system of maize and soybean under intercropping conditions overlapped more than that of each crop under single-cropping, while the distribution of the roots under intercropping tended to be stratified in the middle layer of the soil profile. It is suggested that the root systems of maize and soybean grown under intercropping conditions interpenetrate into the area of the adjacent crop. In contrast, under single-cropping the root systems do not interpenetrate each other, as observed earlier by Pavlychenko (1937) and also reported by Raper and Barber (1970). These phenomena may be ascribed to the fact that under intercropping conditions the root distribution of the crops is different in order to secure the uptake of nutrients or water from soil, as when, in order to minimize competition for light, crops display leaves more horizontally in response to competition.

6.2 Distribution of crop root systems under single-cropping and intercropping conditions in slash and burn field

Field experiments in a slash and burn field were designed to analyze the characteristics of root systems under single-cropping and intercropping conditions employing maize, upland rice and soybean from May through October 1992. The purpose of the experiment was to investigate the situation in a farmer's field in comparison with the results of the preceding section.

6.2.1 Methods

To obtain quantitative root data, the trench profile method and foil method were used for mapping the crop rooting systems and counting root number under single-cropping and intercropping

conditions. These methods were first done by Weaver (1919), and then have been modified by many researchers. The author conducted the field experiment by using the method as follows:

1. A trench was dug transversely to rows with hoe. The position of the trench was a distance of 5 cm from the crop standing position. The length, width and depth of the trench were 1.0 m, 1.0 m and 0.5-0.6 m to the bed rock, respectively.
2. The working face of the profile was smoothed by a spade and knife. Then toothed metal scrapper and paintbrush were used in order to expose the roots out of the soil.
3. Mapping and counting roots were done immediately after exposing. A square grid net is placed against the profile wall and serves a guide. The size of the grids was 5 x 5 cm. The frame which is 1.0 x 0.5 m inner dimensions was made of wood. The grid system consists of black nylon thread. The frame is covered with a transparent plastic sheet (2.0 mm thick). The exposed roots were marked as dots on the sheet with a water-proof felt pen. For counting the roots, the film was removed.
4. The working face of the profile was scratched by using small-toothed scraper and screw drivers due to expose the root system. The root was fixed by hair-pin in order to keep the real position of the rooting systems in the soil profile. After the root systems were exposed, another transparent plastic sheet was placed in front of the profile wall. Then, the exposed root system was traced with a water-proof felt pen, referred to as "root distribution chart" (Reijmerink, 1964).
5. An plastic sheet which was marked with a 2 x 2cm grid -net

was put on the sheet of mapped root in a laboratory. The number of roots in the square grid was counted, and recorded on 5mm section paper. It was called "root number distribution chart". The sheets on which the root system was traced were also used to determine the root system area, the root spread and the pattern. The root system area was determined by automatic area meter, after the sheets of the modeled root systems were cut off.

6.2.2 Results and Discussion

i) Distribution of maize root systems in farmers fields of different land-use histories

In this paper, the root distribution in this paper is represented by the extent of roots observed from a vertical direction in the soil profile, and by the average value of two replications in each slope location of F2 ,F3 and F4.

Fig.6-5 shows the distribution of maize root systems at each sampling point and effective soil depth distribution in F2. The root extent was different in each slope location. In the lower and middle-2 part, the roots extended deeper than in the middle-1 and upper part. In the lower and middle-2 part, the locations are characterized by a deep soil and a gentle sloping face. Contrary to this, the upper and middle-1 part are characterized by a shallow soil and steep sloping face. Moreover, the lateral root distribution in lower and middle-1 were wider than that in middle-2 and upper.

The maize root systems showed a substantially symmetric pattern in all locations of the slope, though the size was different.

Table 6.4 shows a comparison of maize root system area at each slope location in F2, F3 and F4. The areas were also different in size among parts of the slope. In F2, maize root systems occupying the lower and middle-1 part of the slope had a significantly larger area than in the middle-2 and upper part. The area in middle-1 was the smallest, suggesting the effect of soil depth on the root system distribution.

Fig.6-6 shows the root extent differed in each location of the slope in F3. The roots in the middle part extended less in shallower soil than that in lower and upper part, suggesting the effect of the soil depth on roots. The root system showed a symmetric pattern, as in F2. Root system area also was similar, as shown in Table 6.4.

Fig.6-7 shows the root extent was different in each location of the slope in F4. The root system in the middle part was smaller than that of the lower and upper, but with only a slight difference between the middle and upper part. While the vertical extent of the roots was almost the same in every part of the slope, the lateral extent showed a difference between lower and other parts of the slope. The lateral extent of roots in the lower part was larger than that of the middle and upper. The root system also showed a symmetric pattern.

The area of the root systems in lower part was larger in comparison with that of the middle and upper.

Table 6.4 Comparison of root system area of maize among slope locations in fields of different land-use histories

Field	Locations	Root system area(cm2)	Soil depth(cm)	Slope gradient°
2	Lower	2296.9a	80	16
	Middle1	1075.2c	30	23
	Middle2	2189.0a	70	20
	Upper	1582.9b	60	27
3	Lower	1913.5a	84	27
	Middle	1761.1a	30	26
	Upper	2028.2a	40	35
4	Lower	2074.8a	75	13
	Middle	1423.4b	65	18
	Upper	1763.2ab	60	10

Different letters within a column for the comparison among three or four locations in each crop show significant difference at p=0.05

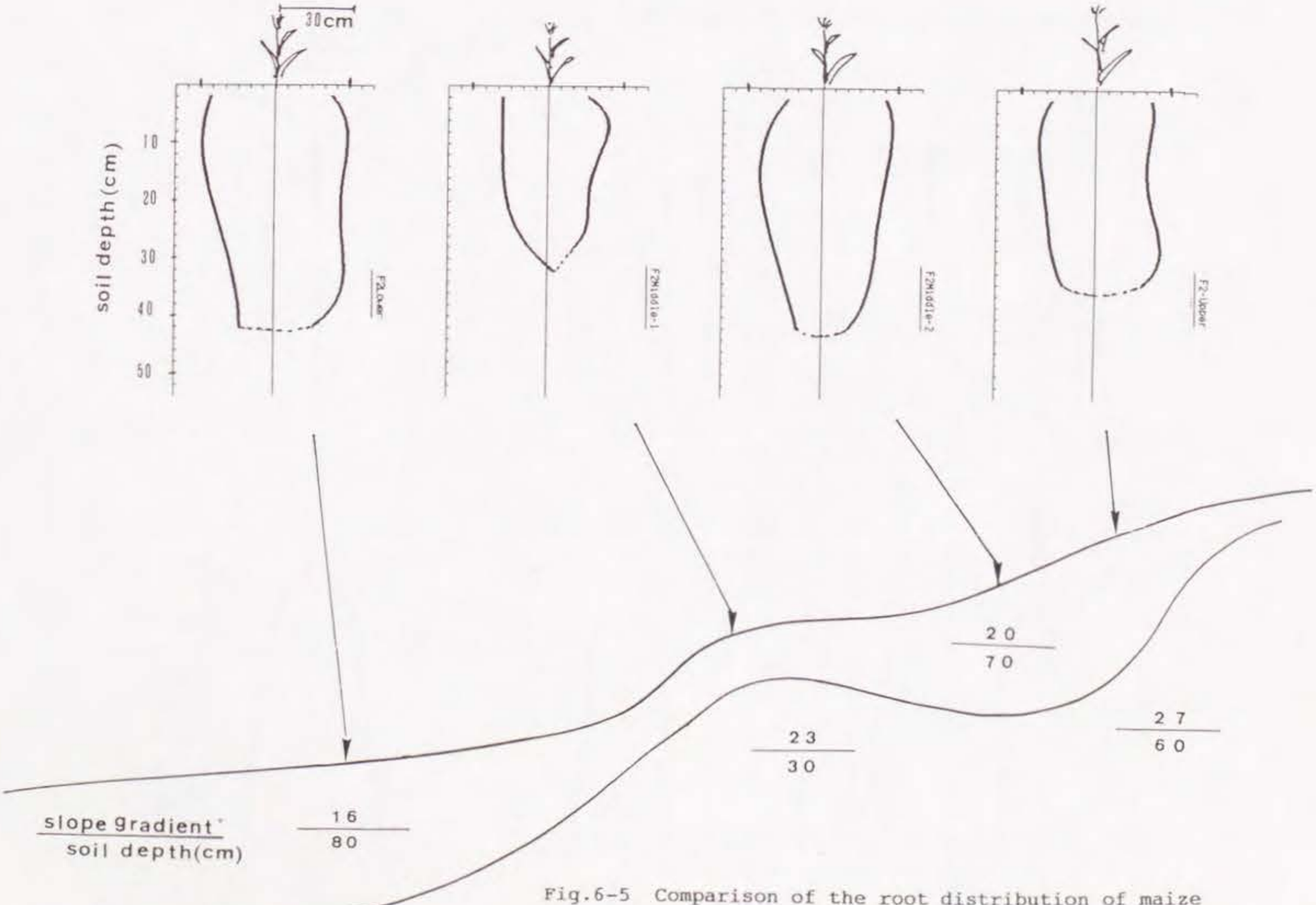


Fig.6-5 Comparison of the root distribution of maize among slope locations in F2

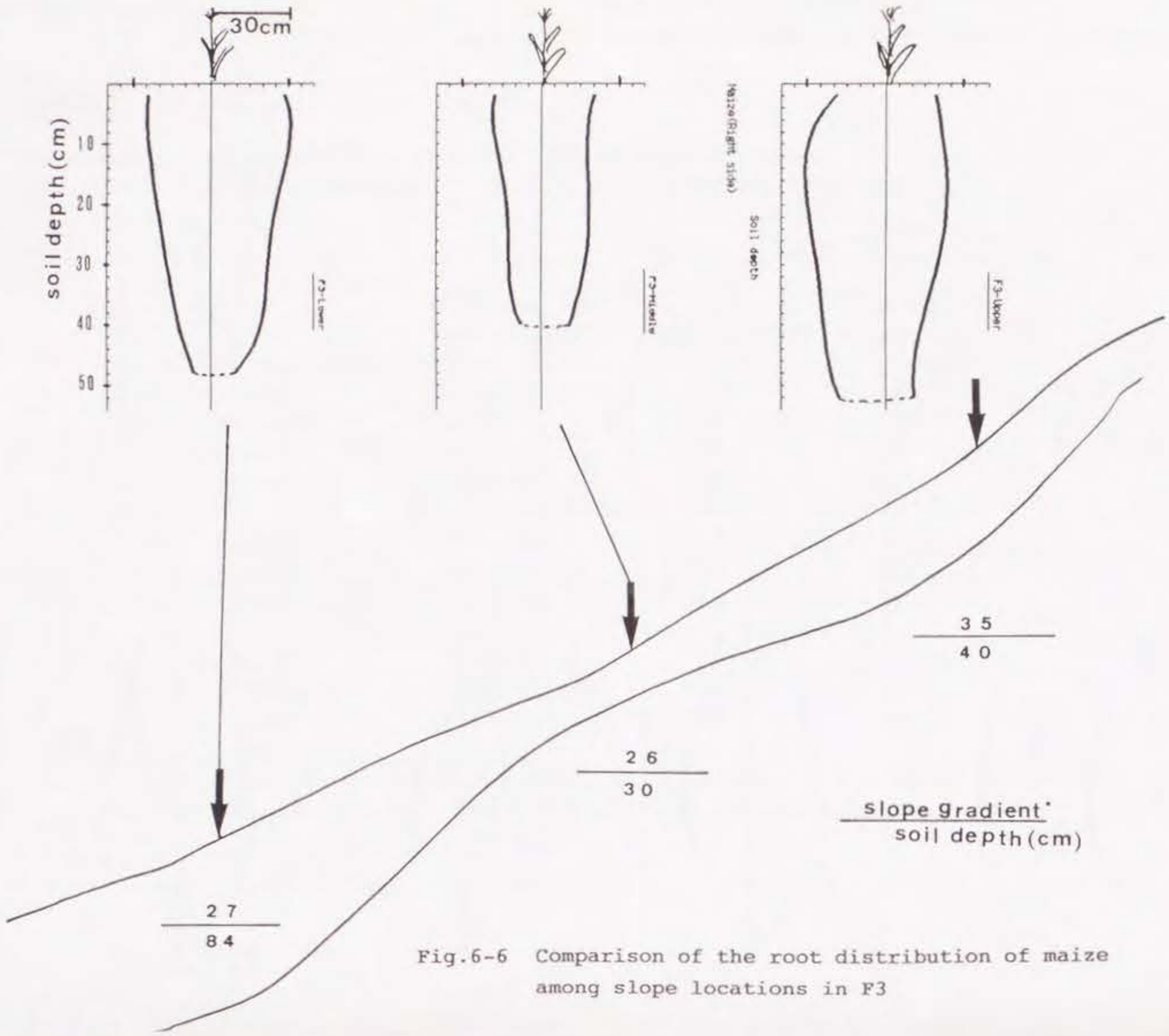


Fig.6-6 Comparison of the root distribution of maize among slope locations in F3

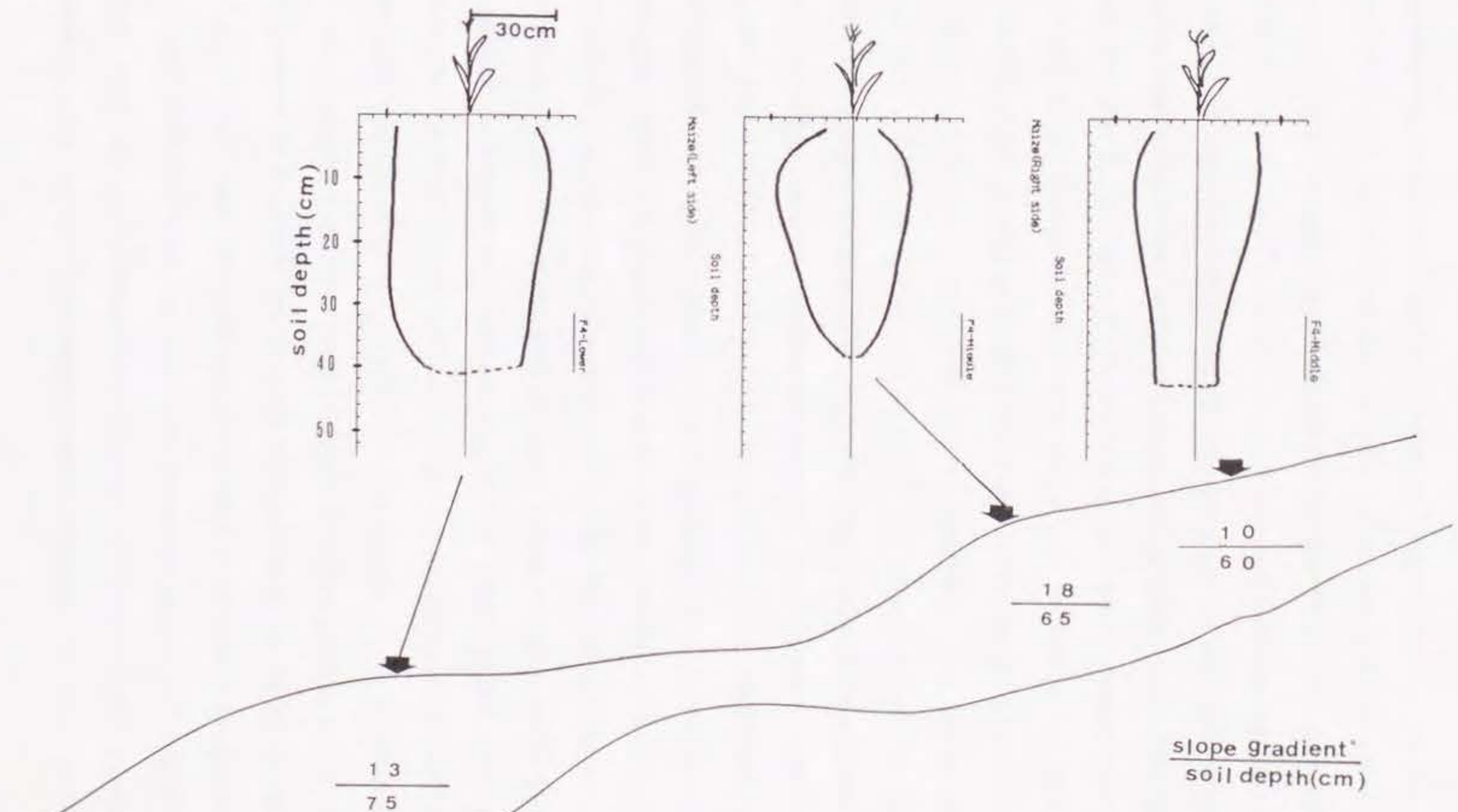


Fig.6-7 Comparison of the root distribution of maize among slope locations in F4

With respect to differences in root system distribution among locations in each field, based on the above-mentioned figures and Table 6.4, the following statements may be made:

1) When maize is grown in deep soil or in lower part of the slope, the root system distribution extends to deeper soil and wider as well. 2) When maize is grown in shallow soil, the root system is restricted to the surface soil layer. 3) Root system patterns of maize planted in wide spacing of more than 80 cm between hills cultivated under single-cropping conditions show a symmetric pattern.

ii) Distribution of maize, upland rice and soybean root systems

As described above, root extent of maize and soybean can be modified by whether the adjacent crop is of the same or a different species, i.e., single-cropping or intercropping condition. In this section, the result obtained in experimental field in Japan was examined in an experiment in a farmer's field. Maize, upland rice and soybean were grown under single-cropping or intercropping conditions with no-tillage or tractor tillage practice, as shown in Fig.5-1. Data on the root system of each crop are shown as a root distribution chart, and area of the root systems which is represented by both a whole area and area divided by central line because the extent of the root system on either side depended on the adjacent crop on that side.

The root distribution in this section is represented by the extent of roots observed from a vertical direction in the soil profile, and by the average value of eight replications in each

treatment.

a) Single-cropping conditions

Maize: Fig.6-8 shows the root distribution of maize cultivated under single-cropping conditions with different tillage practices, such as no-tillage and tractor tillage with burning, and no-tillage with no-burning. The distance between the crops ranged from 25 cm to 30 cm.

The maize roots cultivated by no-tillage practice tend to be restricted to the surface layer, whereas the roots cultivated by tractor tillage tend to extend in the deeper soil layer. The roots in no-burning plot extended in both surface and subsoil layer with almost the same width. Therefore, the root system pattern in no-tillage plots and no-tillage with no-burning plots showed a 'streamline type', and that in tractor tillage plots showed an 'oval type'. Both types show a symmetry.

This difference may be explained by the fact that ash obtained by burning were distributed at the surface in no-tillage plots, whereas in tractor tillage plots ash were dispersed from 20 cm to 30 cm soil depth. This was observed at the time of investigation of soil profile.

The ash is composed of inorganic nutrients, such as potassium, phosphorous, sodium, calcium and magnesium as shown in Table 3.5. Thus, it can be considered that maize roots extend to the places where these nutrients are concentrated. The influence of localized concentrations of nutrients on root morphology has been investigated in more detail by Ishizuka *et al.* (1964) and Drew

(1975).

The area of maize root systems under single-cropping conditions is shown in Table 6.5. The area of maize root system in tractor tillage plot was larger than that in the no-tillage, and that in no-tillage with no-burning plot was the smallest among them. These facts suggest that the effect of tillage and burning on the extent of maize roots is clear.

Upland rice: Fig.6-9 shows the distribution of upland rice root system under single-cropping conditions with no-tillage and tractor tillage practice. Roots in the no-tillage plots extended only into the surface soil layer, whereas those in the tractor tillage plots extended into the deeper soil layer. Therefore, the root system pattern in no-tillage plot showed a 'streamline type', and that in tractor tillage plot showed a 'hanging-bell type'. The pattern in both plots was a substantially symmetric. The difference in type may also be explained from the effect of ash on the roots. The area of upland rice root systems in no-tillage plots was significantly larger than that of the tractor tillage plots (Table 6.5). The result was different from that of the tractor tillage plots. This fact suggests that the effect of tillage on the root system was adverse, because the upland rice roots were small in size compared with maize roots, extended from 20 cm to 30 cm soil depth, and that water holding capacity of the soils tilled by tractor decreased remarkably in the surface soil layer as shown in Fig.6-11. If there is no rainfall for a few days during the growth period, upland rice roots in tractor

tillage plots will be more likely to be subjected to drought conditions than those of the no-tillage plots. Hence, the roots in tractor tillage may be smaller.

Soybean: Fig.6-10 shows the distribution of soybean root systems under single-cropping with no-tillage and tractor tillage practice. The roots in the no-tillage plots were distributed only in the surface soil layer, whereas those in tractor tillage plots were distributed in the deeper soil layer, as were as maize and upland rice. Therefore, the root system pattern in no-tillage plots showed a 'streamline type', and that of the tractor tillage plots showed an 'oval type'. This difference also may be explained by the effect of ash on the roots.

The area of soybean root systems in tractor tillage plots was significantly larger than that in no-tillage plot (Table 6.5). The fact suggests that tractor tillage has no adverse influence on soybean roots, because of the deep rooting.

Based on these facts, the following statements may be made. Maize, upland rice and soybean root systems under single-cropping conditions show a substantially symmetric root distribution on the soil profile, suggesting that the influence of adjacent crop roots on distribution is the same, regardless of species. These root patterns can be classified into three types, i.e., a streamline type, an oval type and a hanging-bell type. The effect of tractor tillage or localized concentration of ash in the soil is large enough to change the root distribution pattern.

Table 6.5 Comparison of root system area between single cropping and intercropping with maize, rice and soybean under different tillage conditions

Crop / Cropping	Root system area(cm2) No-till	Tractor-till
Maize		
Single cropping	751.4c	887.5b
Intercropping		
with rice	1664.9a	1650.2a
with soybean	1068.5b	1474.6a
Rice		
Single cropping	539.5ab	434.5b
Intercropping		
with maize	448.1b	638.4ab
with soybean	706.4a	816.1a
Soybean		
Single cropping	441.0b	621.2ab
Intercropping		
with maize	498.1ab	469.1b
with rice	541.0a	735.8a

Different letters within a column for the comparison among three cropping practices in each crop show significant difference at p=0.05

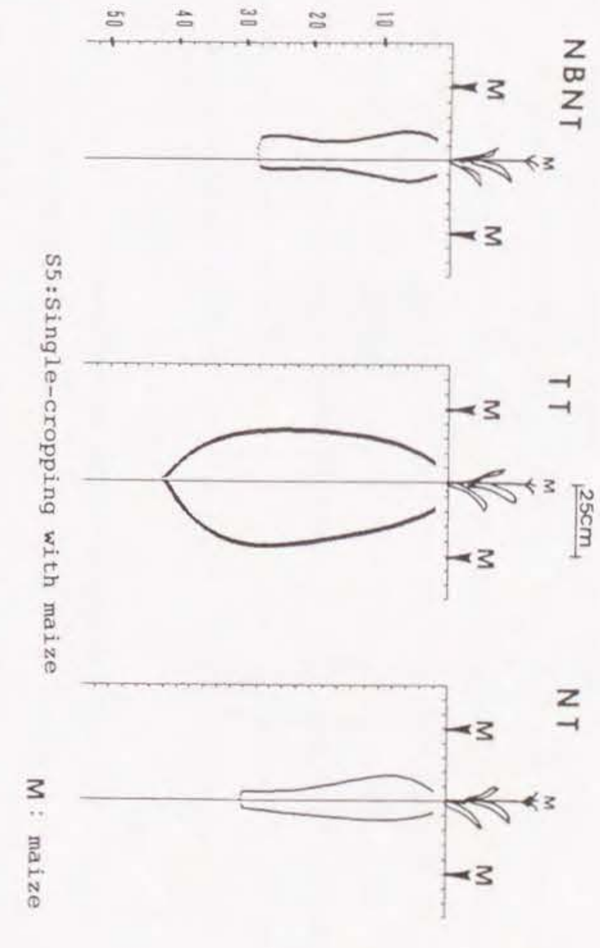


Fig.6-8 Comparison of the root distribution of maize among different tillage conditions in F6

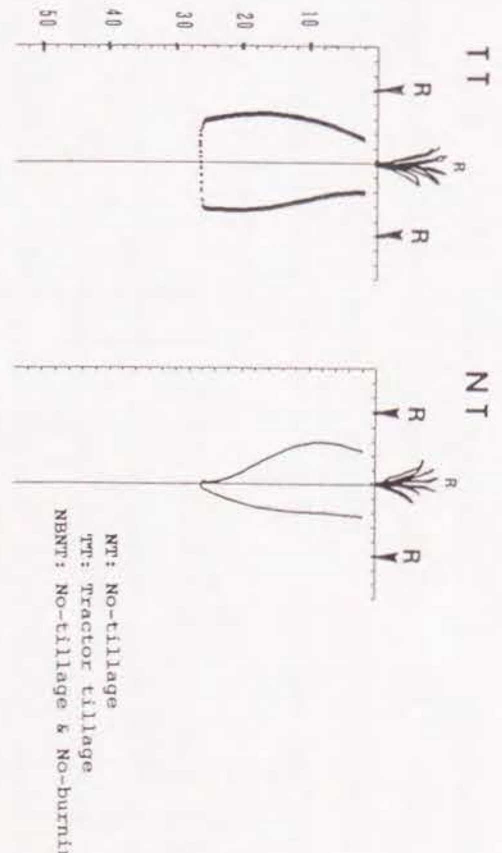


Fig.6-9 Comparison of the root distribution of upland rice between different tillage conditions in F6

▼arrows show hill position of each crop

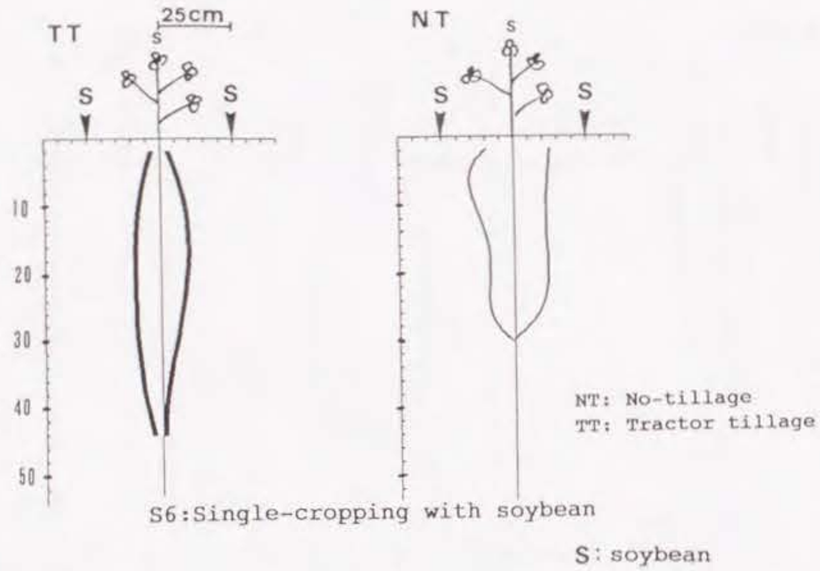


Fig.6-10 Comparison of the root distribution of soybean between different tillage conditions in F6

▼: arrows show hill position of each crop

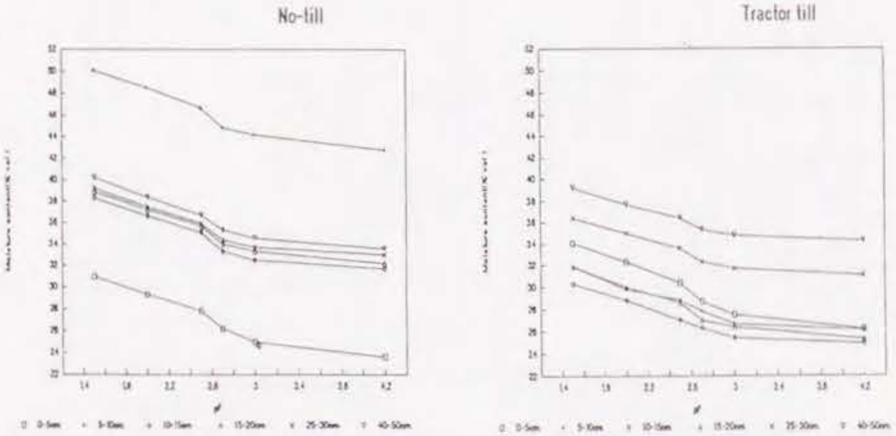


Fig.6-11 Water retention curve of soils under tractor tillage and no-tillage conditions

b) Intercropping conditions

Maize and upland rice: In both no-tillage and tractor tillage plots, the root systems of maize intercropped with upland rice was more developed in the direction of the root system of upland rice, and less developed toward the side of neighbor maize root systems, as shown in Fig.6-12. Hence, the root system of maize showed an asymmetric pattern. The root systems of upland rice also were more developed on the side of maize root systems, and showing an asymmetric pattern.

In both crops, the roots in no-tillage and tractor tillage plots were extended in the surface and the deeper soil layer, respectively, as was the case as under single-cropping conditions. The reason for this may be the same as that for the single-cropping treatments.

The area of maize root systems intercropped with upland rice in no-tillage plot was not different from that of the tractor tillage plots. However, the area of upland rice intercropped with maize in tractor tillage plots was larger than that of the no-tillage plots as shown in Table 6.5.

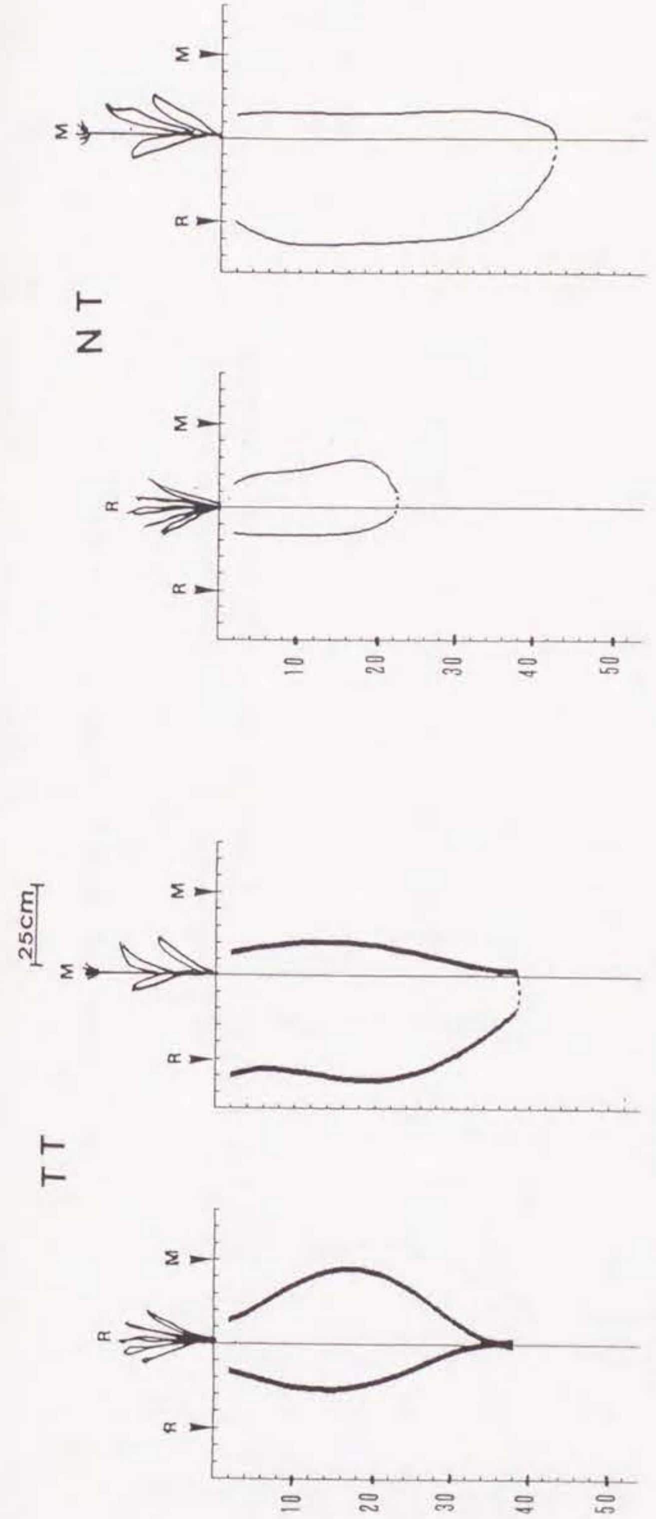
Maize and soybean: In both no-tillage and tractor tillage plots, the root systems of maize intercropped with soybean were more developed toward the side of the soybean root systems, and the soybean root systems intercropped with maize were more developed toward the maize root system side, as shown in Fig.6-13. Therefore, these root systems showed an asymmetric pattern.

The area of maize root systems intercropped with soybean in tractor tillage plots was larger than that of the no-tillage

Table 6.6 Comparison of divided root system area at hill position according to adjacent crop under different tillage conditions

Crop	Cropping / Adjacent crop	No-till	Tractor-till	No-burn & No-till
		Root system area(cm2)		
Maize				
	Single cropping			
	Maize side	399.0a	421.3a	302.4a
	Maize side	370.9a	479.6a	289.8a
	Intercropping with Rice			
	Maize side	568.3b	693.4b	
	Rice side	1132.3a	992.0a	
	Intercropping with Soybean			
	Maize side	424.2b	541.0a	
	Soybean side	673.7a	956.8a	
Rice				
	Single cropping			
	Rice side	269.9a	228.1a	
	Rice side	266.5a	200.3a	
	Intercropping with Maize			
	Rice side	204.1b	300.7b	
	Maize side	256.2a	351.5a	
	Intercropping with Soybean			
	Rice side	288.1b	303.7b	
	Soybean side	440.2a	526.3a	
Soybean				
	Single cropping			
	Soybean side	225.9a	325.5a	
	Soybean side	223.4a	315.0a	
	Intercropping with Maize			
	Soybean side	201.6a	311.6a	
	Maize side	201.2a	270.9a	
	Intercropping with Rice			
	Soybean side	194.9b	209.2b	
	Rice side	348.6a	533.4a	

Different letters within a column for the comparison between two crop sides in each crop show significant difference at p=0.05



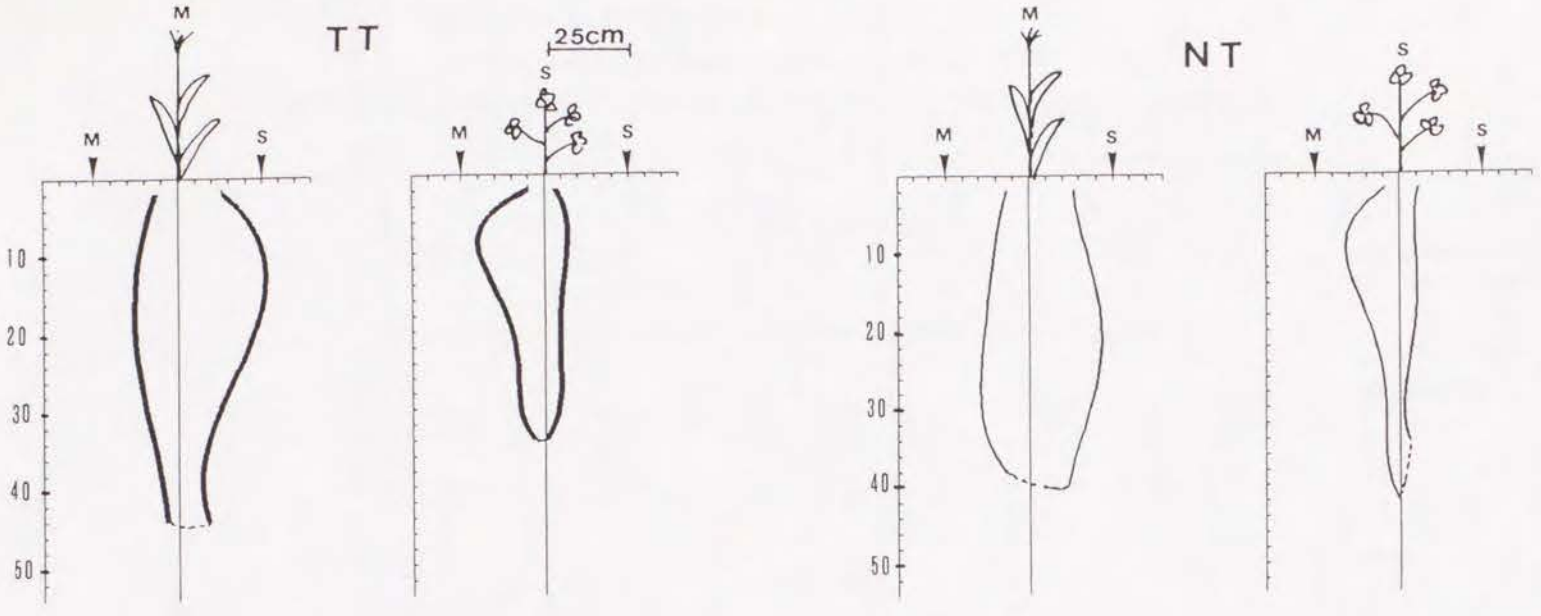
M : maize
R : upland rice

NT: No-tillage
TT: Tractor tillage

S1:Intercropping with maize and upland rice

Fig.6-12 Root distribution of maize and upland rice under intercropping conditions in no-tillage and tractor tillage plots

▼:arrows show hill position of each crop



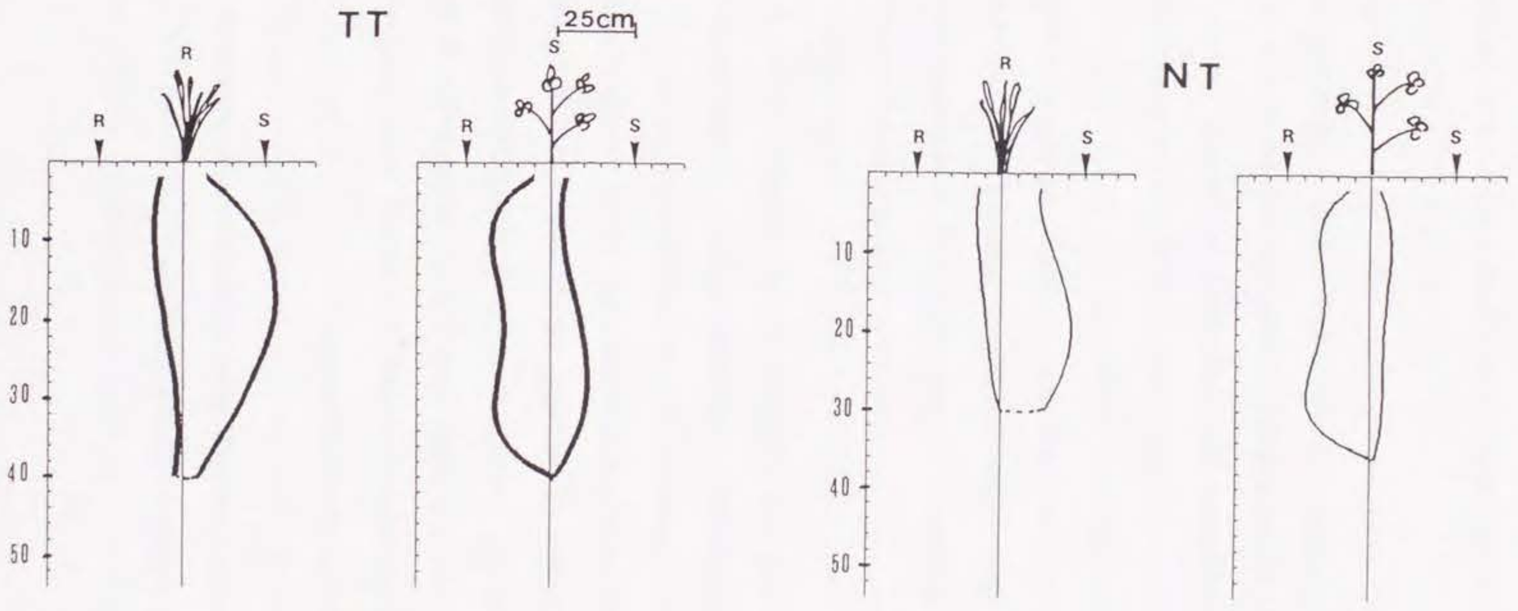
S3:Intercropping with soybean and maize

M : maize
S : soybean

NT: No-tillage
TT: Tractor tillage

Fig.6-13 Root distribution of maize and soybean under intercropping conditions in no-tillage and tractor tillage plots

▼: arrows show hill position of each crop



S2:Intercropping with upland rice and soybean

R : upland rice
S : soybean

NT: No-tillage
TT: Tractor tillage

Fig.6-14 Root distribution of upland rice and soybean under intercropping conditions in no-tillage and tractor tillage plots

▼: arrows show hill position of each crop plots, whereas the area of soybean root systems intercropped with maize was not different between no-tillage and tractor tillage plots.

Upland rice and soybean: In both no-tillage and tractor tillage plots, the root systems of soybean intercropped with upland rice were larger toward the side of upland rice root systems. The root systems of upland rice intercropped with soybean showed a similar tendency, as shown in Fig.6-14. Therefore, these root system patterns showed an asymmetric pattern.

The area of soybean root systems in tractor tillage plots was significantly larger than that in no-tillage plots, whereas the area of upland rice root systems in no-tillage plot was not significantly different from that in tractor tillage plot (Table 6.5).

Based on these facts, the following statements may be made. Maize, upland rice and soybean root systems under intercropping conditions are strongly affected if the adjacent crop is a different species, because root pattern and root system area were modified according to the adjacent crop species. Tillage practices under intercropping conditions and single-cropping conditions affect on the root pattern and the root system area. The influence of localized concentration of ash on root pattern may vary depending on the crop combination.

c) Comparison of characteristics of root distribution between single-cropping and intercropping systems

There are marked differences in the distribution of maize,

upland rice and soybean root systems between under single-cropping and intercropping conditions. The results may be described as follows.

Maize: Fig.6-15 shows the comparison of the distribution of maize roots in different cropping systems. In both no-tillage and tractor tillage plots, roots under single-cropping conditions showed a substantially symmetric pattern, whereas the roots under intercropping conditions, in maize intercropped with either upland rice or soybean, showed an asymmetric pattern. In the case of intercropping systems, maize root systems on the side of different kind of crop species were extended larger than that of same species side.

Furthermore, the area of maize root systems under intercropping was much larger than that under single-cropping, particularly in the case of intercropping with upland rice, as shown in Table 6.5. To represent these facts more clearly, the root system area was divided into two parts by a line beneath the hill positions, as shown in Table 6.6. In the case of single-cropping, the area divided into two parts were not different in each tillage plot, but in the case of intercropping, the area on the different crop species side was much larger than that of same species side, in both tillage plots. These facts suggest that root development in intercropping systems is strongly influenced depending on the root size of the companion crop, because the root system of upland rice is much smaller than that of maize.

Upland rice: Fig.6-16 shows a comparison of the distribution of upland rice root systems in different cropping systems. The root system pattern of upland rice showed an almost similar tendency to that of maize, i.e., a symmetric pattern in single-cropping and an asymmetric pattern in both intercropping systems. In the case of intercropping systems, the root system on the side of different crop species was larger than that of same species.

In tractor tillage plots, the area of upland rice root systems intercropped with soybean was larger than that under single-cropping conditions, whereas that intercropped with maize was not significantly different, as shown in Table 6.6. On the other hand, in no-tillage plots, the root system area intercropped with soybean was larger than when grown with maize, although these was no difference between single-cropping and intercropping.

In single-cropping plots, there were no differences in area between the two parts of the divided root system area, but in intercropping plots either with soybean or maize, root system area was significantly larger on the different crop species side compared with the same species side (Table 6.6).

Soybean: Fig.6-17 shows a comparison of the distribution of soybean root systems in different cropping systems. The root systems of soybean under single cropping and intercropping were similar to the other crops, i.e., a symmetric pattern in single-cropping and an asymmetric pattern in intercropping. The roots were extended more on the different crop species side in comparison with the same species side. The area of soybean root

systems intercropped with rice, in the case of no-tillage, was significantly larger than that in single-cropping plots. The area of soybean root systems intercropped with maize was not significantly different from that of the single-cropping plots. On the other hand, the area in tractor tillage plots intercropped with rice was larger than when grown with maize, although there was no difference between single-cropping and intercropping as shown in Table 6.5.

When the root system area was divided into two parts, in the case of single-cropping plots and intercropped with maize, there were no significant differences. In the case of the area of soybean root systems intercropped with rice, the different crop species side was very large in comparison with the same species side (Table 6.6).

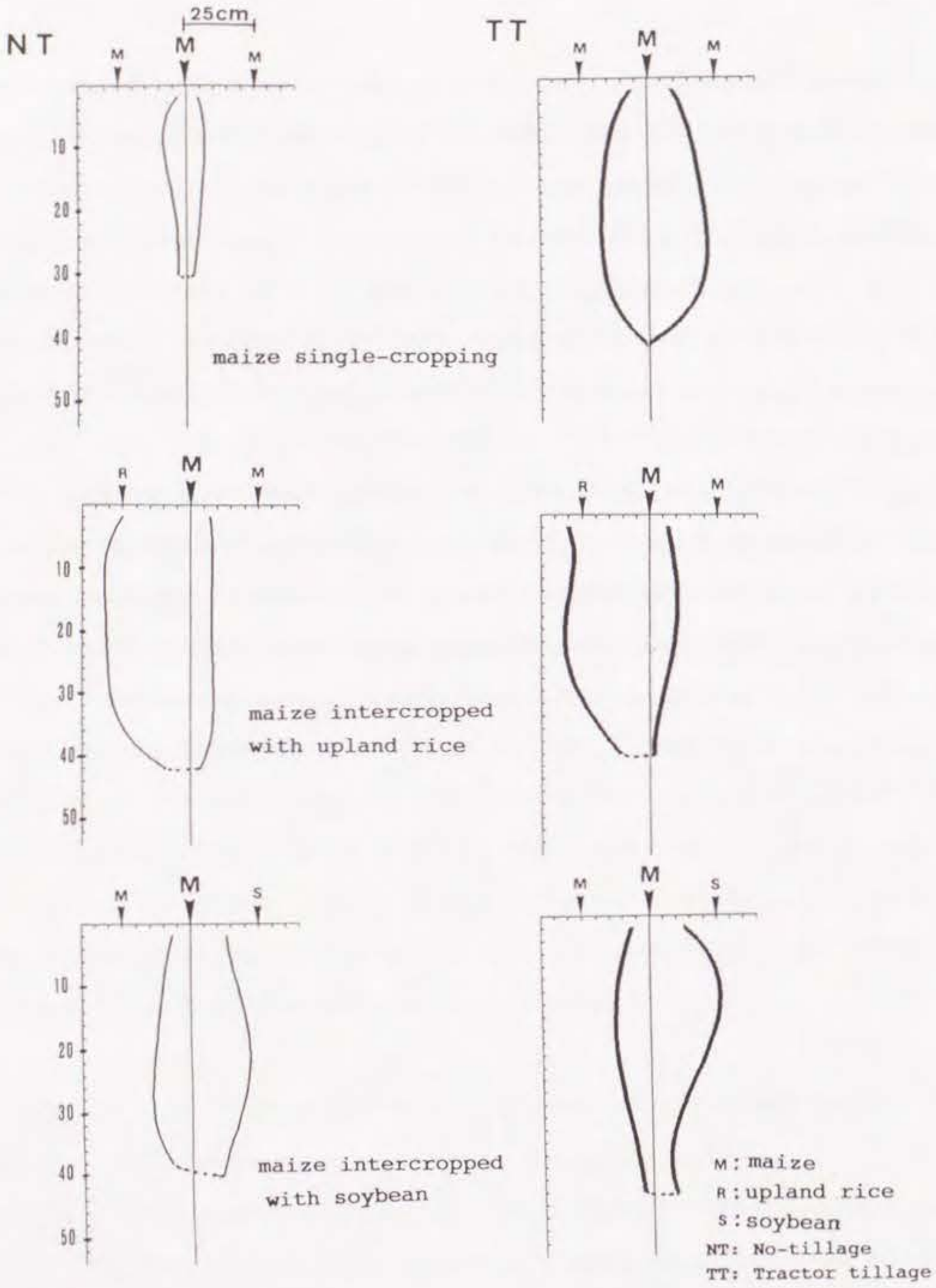


Fig.6-15 Comparison of the distribution of maize roots among different cropping systems under no-tillage and tractor tillage conditions

▼: arrows show hill position of each crop

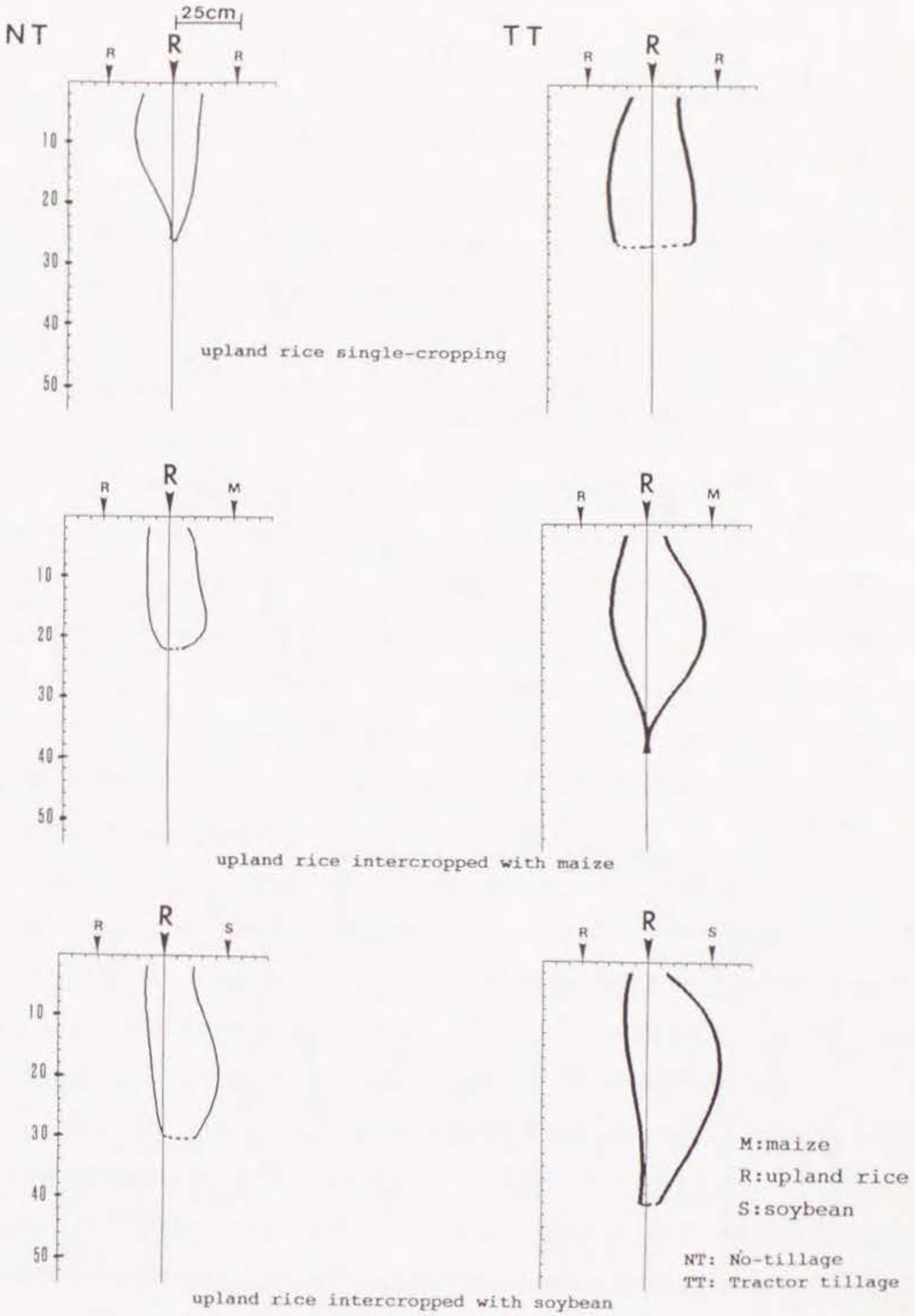


Fig.6-16 Comparison of the distribution of upland rice roots among different cropping systems under no-tillage and tractor tillage conditions

▼: arrows show hill position of each crop

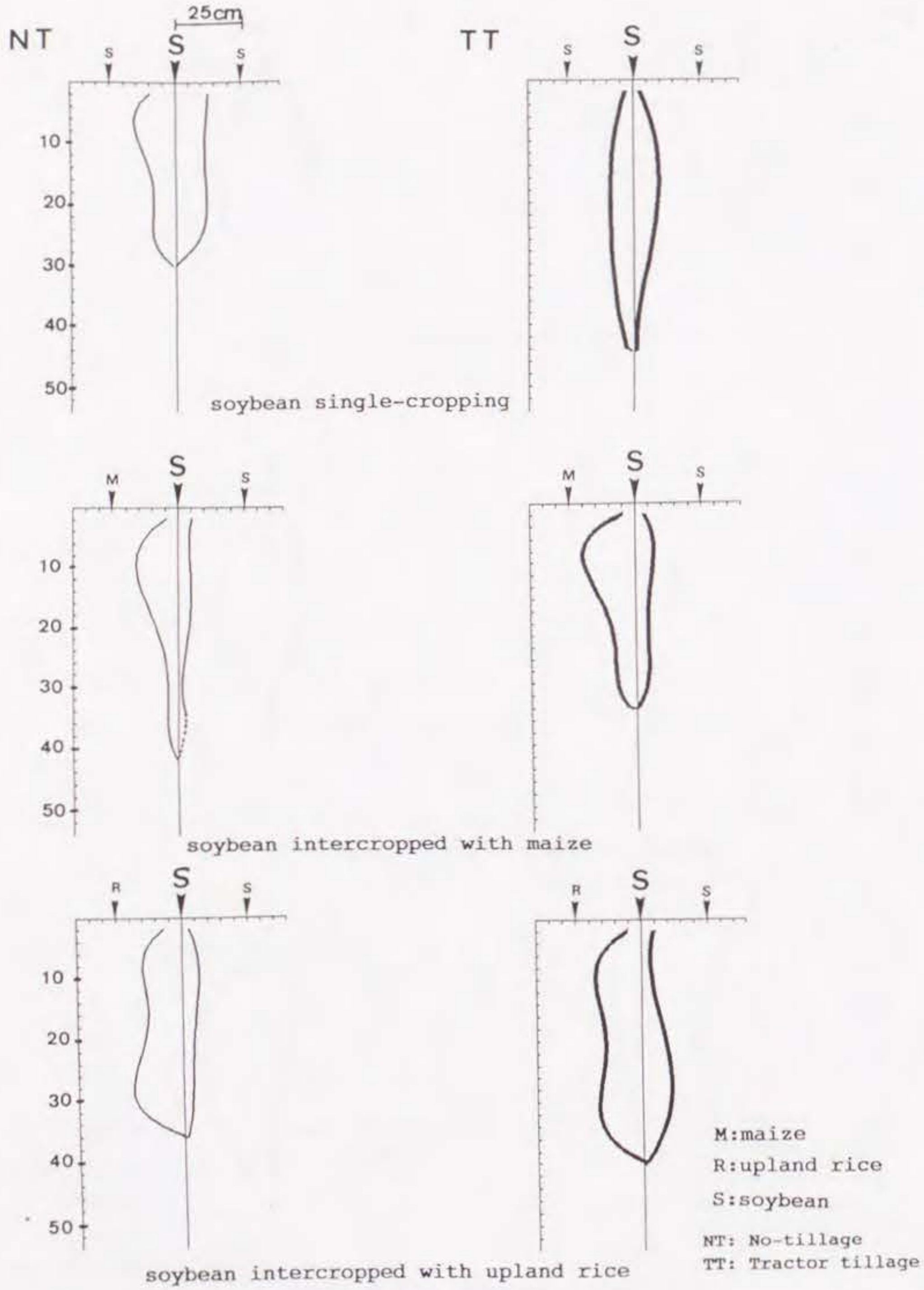


Fig.6-17 Comparison of the distribution of soybean roots among different cropping systems under no-tillage and tractor tillage conditions

▼:arrows show hill position of each crop

CHAPTER 7 Summary

7.1 Ecological changes in farmers sloping fields of the different land-use histories

i) Changes in soil fertility and the influence on crop production

A soil survey which includes description of the soil profile, investigations of effective soil depth distribution and gravel contents in soil, and soil analyses of the chemical and physical properties were made in each field of different land-use histories, as described in Chapter 3. Based on the results obtained from the soil survey, it is concluded that the effect of topography on soil fertility is rather stronger than that of differences in land-use histories.

When soil fertility is estimated by the chemical properties, it is necessary to determine the fine earth fraction per unit volume, in the case of a soil containing the higher gravel contents. In the study fields, the gravel contents in the soil differed in each part of the slope. The gravel contents in the upper part of slope is higher than that in the lower part of slope. The larger slope gradient is, the higher gravel contents become. This suggests that the amount of the fine earth fraction (less than 0.2 cm), which is one factor determining soil CEC is low in the steeper or in the upper part of a slope. Therefore, results are modified with respect to gravel content but not the fine earth fraction to evaluate fertility of field soil. They showed a lower amount of exchangeable cations, total carbon, total nitrogen, clay content, and available phosphorous.

On the other hand, some factors affecting the soil fertility are extracted by using a principal component analysis with varimax rotation. Based on the results, The following differences of fertility status among the fields may be noted.

In the state of the field just after clearing, as F5, the value of soil pH is low and the amount of exchangeable Al is high in comparison with that of successively cropped fields. Since the exchangeable cation contents in a deeper solum is low, Al-saturation is relatively high in it. This acidification and low cation content may be caused by leaching during the fallowed period. On the other hand, the soil in successive cropping fields may be ameliorated by ash addition after burning. The effect of the ash on the soil may be sustained, in spite of both the utilization of basic cations by crops and leaching of cations by rainfall. A clear explanation for this can not be made in the study.

Tillage affects the physical properties of soil, particularly the water holding capacity and soil microbial activity. The soils plowed by tractor may exhibit high hydraulic conductivity and low water holding capacity compared with no-tillage soils. Based on run-off data, tractor tillage may be effective on reducing the amounts of run-off compared with no-tillage, due to an increase in macro pores and the surface roughness of the soil by the tillage. However, tractor tillage may cause serious soil erosion, especially sheet erosion, as observed at other sloping fields

elsewhere in Thailand.

Grain yields and dry matter content were measured to estimate the influence of soil fertility on crop production. Based on the results obtained from statistical analysis, the following statements may be made: High grain yields and dry matter content of maize were obtained in the lower part of slope, which has a thick effective soil layer. The layer contains little gravel, and/or may be of ameliorated soil pH. The yields and dry matter content in the upper part of slope of shallower solum and/or under acid conditions were lower. These facts suggest that crop production is more strongly related to soil depth, and to soil condition ameliorated by ash rather than to differences of land-use history. This should be kept in mind when crop productivity in a slash and burn field is estimated.

ii) Weed dynamics and the influence on crop production

It is widely recognized that one of the most serious problem for shifting cultivators as well as all upland farmers is difficulty in suppressing weeds. The decrease of crop production and abandonment of their field is caused not only by the decline in soil fertility but also by weed infestation (Pendleton 1948, Nye and Greenland 1960). The same impression was obtained from the interview with farmers in the study area. Therefore, it is necessary to develop effective practices for weed control, but only a few data on weed dynamics and the ecological habits in slash and burn field are available.

In this study (as described in Chapter 4), species number and dry matter content of weed were investigated in each field having different land-use histories, during the dry season and the rainy season in 1991. The total number of weed species observed was 70 consisting of 12 species of herbaceous species and 58 woody species, indicating a diversity of woody species. On the other hand, herbaceous weeds in successive cropping fields obviously dominated in total number of plant compared with coppice shoots, whereas coppice shoots in one year cropping field dominated even in tractor tillage plots. These facts suggest that successive cropping decreases both the number of woody species and the total number of coppice shoots, and the decrease causes suppression of tree regeneration.

In the dry season, *Eupatrium odoratum*, *Mimosa invisa* and *Ageratum conyzoides* were the main weed species in all fields, particularly *E. odoratum* dominated, while *A. conyzoides* replaced *E. odoratum* as a dominant species in the rainy season. This may be explained from that *E. odoratum* is classified as perennial shrub and a drought resistant species which can survive the dry season, while *A. conyzoides* is an annual herb that withers during in the dry season. On the other hand, it was observed that the other weed species tended to be confined to specific locations in each part of a slope or field.

The growth of weeds in steep sloping land was superior to that in a gentle sloping land, suggesting that lower yield of maize in a steep sloping land is not only attributable to low fertility, but also to serious growth inhibition by weeds. Such a location was particularly infested with *Imperata cylindrica*. These facts

indicate that land productivity among locations does not differ very much. Therefore, it is necessary to consider how to use such locations, for example how to produce the mulching materials or perennial crops.

7.2 Ecological characteristics of roots under single-cropping and intercropping conditions

It is generally recognized that intercropping systems have many advantages including better utilization of environmental factors, greater yield stability in variable environments, soil protection, and regularity of food supply (Beets 1982). These are owing to the ecological diversity within the various pattern of crop combination and crop sequence (Lal 1986). Such a complex systems give rise to a complexity of research questions, compared to monoculture, and it is difficult to evaluate what factors most constrain production (Parkhurst and Francis 1984). Much of intercropping study has focused on the question: "does the intercropping offer some sort of advantage over the associated monoculture?" or "if the intercropping is advantageous, why?" (Vandermeer,1989). To answer these questions, most part of the present study have been carried out under conditions of the experimental station.

The author examined the advantage of intercropping systems focusing on the under-ground interrelationships between two kinds of intercropped plants. At first, the experiment was carried out in the experimental field in order to minimized the environmental factors (Chapter 6). Next, similar experiments were carried out on-farm in a slash and burn field to check the applicability of the results obtained in the former experiment. These results are summarized as follows:

1) Results obtained from the experimental field in Japan.

When maize and soybean was intercropped, their root systems expanded markedly compared with those in single-cropping. The overlapping areas of the root systems of maize and soybean under intercropping conditions were significantly larger than under single-cropping conditions. An increase in root number under intercropping conditions was also observed.

2) Results obtained from on-farm experiment in Thailand.

In a sloping land, the distribution of maize root systems under single-cropping conditions was restricted depending on the soil depth, and the root system showed a symmetric pattern. In the field just after clearing, the distribution of maize, upland rice and soybean root systems under tractor tillage conditions extended in the deeper soil layer, compared with that under no-tillage, resulting from differences in the distribution of ash in the soil. Under tractor-tillage, the root systems of maize, upland rice and soybean showed an oval type, a hanging-bell type and an oval type, respectively. Under no-tillage, they all showed a streamline type. On the other hand, maize, upland rice and soybean under intercropping conditions extended their root systems toward those of different species, not toward the same species. Thus, all of the root systems of them showed an asymmetric pattern. The area of root systems under intercropping

conditions was significantly larger than that under single-cropping.

From the facts described above, the author concludes that the root systems under single-cropping conditions are subjected to the strong influence of the adjacent crop roots, and the interpenetration of root systems is restricted, while under intercropping conditions they can interpenetrate or overlap, and hence have a large root system area. This can be interpreted as an advantageous aspect of intercropping. Furthermore, judging from the orientation of roots, the fertilization effect of ash by burning can be expected, showing the advantageous aspect for crop production in a slash and burn field. Tractor tillage so far may be effective for weed control and increase of a crop productivity. The author cannot efface the most serious problems which may possibly arise as a erosion and/or drastic decrease of crop production.

7.3 Further study needed for developing a continuous upland farming in the monsoon tropics

It is necessary to increase crop productivity within the presently cultivated area in order to reduce the need to clear new lands for farming and to sustain the forest resource in the tropics (Lal 1986). Therefore, ecologically compatible upland farming systems have to be developed in the present slash and burn fields. In this study, the author pointed out the following three facts. First, a crop productivity in a steep sloping land markedly decreases due to the shallow soil depth and high gravel contents. Next, intercropping systems from the point of view of the distribution of intercropped crop roots are capable of increasing the productivity compared with single-cropping. And finally, the fertilization effect of ash exerts the soil fertility in slash and burn field.

Based on these considerations, the following recommendations and necessity of further study are shown.

1) Crop cultivation at a steep location in sloping field should be avoided. Instead, the controllable weeds, as mulching materials, or perennial crops should be grown.

2) If mulching materials are sufficient to cover fields overall, ash obtained by burning should be incorporated into the surface layer by hoe, and then completely covered with mulch before the first shower.

3) Intercropping systems which consist of cereal crops and leguminous crops are worth trying for the purpose of effective use of land and the other advantages.

4) The beneficial effect of tractor tillage practiced in sloping land may be temporary; it is possible to spoil the fields from the long-term point of view. This is one of the subjects for a further study.

5) A cropping system in slash and burn field, which consists of annual and perennial crops, should be investigated to sustain upland farming in the monsoon tropics.

References

Abruna, F. Perez, R. Vincente, J. Pearson, R.W. and Silva, S. 1974: Response of Corn to Acidity Factors in Eight Tropical Soils. J. Agric. Univ. P. R. 58: 59-77.

Beets, W.C 1982: Multiple Cropping and Tropical Farming Systems. Westview press. Colorado, U.S.A.

Böhm, W. 1980: Methods of Studying Root Systems. Ecological Studies, Vol. 33, Springer-Verlage, N.Y.

Dent.F.S. 1992: Environmental Issues in Land and water Development, A Requairal Perspective. RARA publication 1992, F.A.O. pp. 52-74.

Drew, M.C., 1975: Comparison of the effects of a localized supply of phosphate, nitrate, ammonium and potassium on the growth of the seminal root system, and the shoot, in barley. New Phytol. 75:479-490.

Drew, M.C. and Saker, L.R., 1975: Nutrient supply and the growth of the seminal root system in barley.II Localized, compensatory increase in lateral root growth and rates of nitrate uptake when nitrate supply is restricted to only part of the root system. J. exp. Bot., 26:79-90.

Fox, R.H. 1979: Soil pH, Aluminum Saturation, and Corn Grain Yield. Soil Sci. 127: 330-334.

Greenland, D.J. 1975: Bringing the Green Revplition to the Shifting Cultivator. Science. 28:841-844.

Gregory, P.J. 1988: Growth and functioning of plant roots. In: Russel's Soil Conditions and Plant Growth. (Alan, W. eds.) Longman Group UK Ltd., England.

Hall, R.L. 1974: Analysis of the nature of interference between plants of different species. 1.Concepts and extension of de Wit analysis to examine effects. Aust. J., Agric. Res., 25:739-747.

Hayashi,Y. and Kyuma,K.,1989: Effect of Soil Aluminum on Maize. Japan J.Trop. Agr. 33:268-278.

Hirai,H., Yoshikawa, K., Funakawa, S., and Kyuma K., 1991: Characteristics of brown forest soils developed under different bio-climatic conditions in the Kinki District with special reference to their pedogenetic process. Soil Sci., Plant Nutr., 37:639-649.

Hithuda, K. and Tanaka, A 1983: Chemical characteristics of acid soils from plant nutritional view point. Memories of the college of Agrc. Hokkaido Univ., 13:485-493. (in Japanese)

Houghton, R.A., Boone, R.D., Melillo, J.M., Palm, C.A., Woodwell, G.M., Mayers, N., Moore III, B. and Skole, D.L., 1985: Net flux of carbon dioxide from tropical forests in 1980, Nature 316:617-620.

Ishizuka, Y., Hayashi, M., Ogata, A and Harada, I. 1964: Study on location of fertilization for upland crops. Jpn., J., Soil Sci., Plant Nutr., 35: 159-164.

Jurion, F. and Henry, J., 1969: Can primitive farming be modernized? INEAc, Ser. HORS. Institute National Pour L'Etude Agronomique du Congo, Brussels.

Koeppen,W. 1931: Grundriss der klimakunde. Berlin, de Granter.

Kosaki,T. and Juo,A.S.R. 1989a: Multivariate approach to grouping soils in small fields. Soil Sci.Plant Nutr., 35:469-477.

Kosaki,T., Wasano, K. and Juo, A.S.R. 1989b: Multivariate statistical analysis of yield- determing factors. Soil Sci. Plant Nutr., 35: 597-607.

Kyuma,K. and Pairintra,C. eds, 1983: Shifting Cultivation, An Experiment at Nam Phrom, Northeast Thailand, and Its Implications for Upland Farming in the Monsoon Tropics, Faculty of Agriculture, Kyoto University.

Kyuma,K. 1972: Numerical classification of the climate of south and southeast Asia. Southeast Asian Studies 9:502-521.

Lal, R. 1986: Soil Surface Management in the Tropics for Intensive Land Use and High and Sustained Production. In: Advances in Soil Science, Vol. 5. Springer-Verlage, N.Y.

Murakami, H. 1986: Polder. In: Acid sulfate soil. Urban Kubota. 25:12-21. (in Japanese)

Miyake, K. 1976: The toxication of soluble aluminum salts upon thr growth of the rice plant. Jour, Biol, Chem, 25: 23-28

Nakano,K. 1978: An ecological study of swidden agriculture at a village in northern Thailand. Southeast Asian Studies 16:411-446.

Newton,K., 1960: Shifting cultivation and crop rotation in the tropics. Papua New Guinea Agr. J., 13:81-118.

Noda, K., Teerawatsakul, M, Prakongvongs, C and Chaiwirtnukul, L 1984: Major Weeds In Thailand. National Weed Science Research Institute Project, Bangkok.

Nye,P.H and D.J.Greenland 1960: The soil under shifting cultivation. CBS Tech. Commun. No.51, Harpenden.

Nye, P.H. and D.J.Greenland 1964: Changes in the soil after clearing a tropical forest. Plant and soil 21: 101-112.

Office of Agricultural Economics, 1968-1989: Agricultural Statistics of Thailand. Ministry of Agriculture and Cooperatives, Bangkok.

Okagawa, N. 1984: Distribution and useful of acid soils in the world. In: Acid soils and the agricultural use. (Tanaka, A eds.) Hakuyusya (Tokyo) 21-49. (in Japanese)

Parkhurst, A.M. and Francis, C.A 1986: Research Methods for Multiple Cropping. In: Multiple Cropping Systems. (Francis, C.A. eds.) Macmillan Publish. Company, N.Y., 285-316.

Pavlychenco, T.K. 1937: Quantative study of the entire root systems of weed and crop plants under field conditions. Ecology. 18:62-79.

Pendleton, J.W., Belen, C.D., and Seif, R.D., 1963: Alternating strips of corn and soybean versus solid plantings, Agron. J. 55:293-295.

Raper, C.D. and Barber, S.A. 1970: Rooting system of soybeans: 1. Differences on root morphology among varieties. Agron. J., 62:581-584.

Reijmerink, A., 1964: A new method for recording root distribution. Meded. Dir. Tuinbouw 27: 42-49. (in Dutch with English summary)

Royal Thai Survey Department. 1977: Vegetation map of Thailand. Royal Thai Survey Department, Bangkok.

Russell, R.S. 1982: Plant Root Systems, Their function and interaction with the soil. McGraw-Hill Book Company (UK) Ltd., England.

Sanchez, P. A., 1973: Soil management under shifting cultivation. In: A Review of Soils Research in Tropical Latin America. North Carolina Agr. Exp. Sta. Tech. Bull., 219: 46-67.

Sanchez, P.A. 1976: Properties and Management of Soils in the Tropics. 223-253, Jhon Wiley & Sons Ltd., N.Y.

Sasaki, T. 1932: A Preliminary Report on the Form of the Root System in Rice Plants. Jpn., Crop Sci., 4:200-225.

Saxena, S.C. and Chandel, A.S. 1986: Effect of maize on physio-agronomic attributes of soybean in maize-soybean intercropping. Indian J., Agric. Sci., 56:771-775.

Syoji, S. 1983: Mineralogical characteristics of volcanic ash soil. In: Volcanic ash soil-pedogenesis, characteristics and classification. (Japanese society of soil science and plant nutrition eds.) Hakuyusha (Tokyo) 31-72. (in Japanese)

Tanaka, A. and Hayakawa, Y. 1974: Differences of acid tolerance among crop species. I. Differences of low pH tolerance among species. Jpn., J., Soil Sci. Plant Nutr., 45:561-570 (in Japanese)

Tanaka, A. and Hayakawa, Y. 1975: Ditto. II. Differences of Al and Mn tolerance among species. Jpn., J., Soil Sci. Plant Nutr., 46:415-419. (in Japanese)

Tathuyama, K., Yamamoto, H., Sasaki, A. and Egawa, H. 1984: A method for cellulose composition using Benchkote sheet. Jpn., J., Soil Sci. Plant Nutr., 55:180-182. (in Japanese)

Trenbath, B.R. 1974: Biomass productivity of mixtures. Adv. Agron.J., 26:177-210.

Vandermeer, J. 1989: The Ecology of Intercropping. Cambridge Univ. Press, N.Y.

Weever, J.E. 1926: Root Development of Field Crops. McGraw-Hill Book Company, N.Y.

Wrigley, G. 1981: Tropical Agriculture, The Development of Production. Longman Group UK Ltd, Harlow, England.

Zandstra, H.G., Price, E.C., Litsinger, J. A. and Morris, R.A. 1981: A Methodology for On-Farm Cropping Systems Research. I.R.R.I., Manila.

Appendix 1

Appendix: Soil Profile Description

Location: T21
Topography: South 13^{o} east facing slope, gradient 9^{o}, on the moderately steep mountainous slope
Altitude: 512m

Hor.	Depth (cm)	Description
Ap1	0-7	Dull orange (5YR6/3) when dry, Very dark reddish brown (5YR2/4) when moist; dry; silty clay; moderate fine angular blocky, slightly hard; no sticky, plastic; many roots; common strongly weathered gravels; clear smooth boundary to
Ap2	7-17	Dull reddish brown (5YR5/4) when dry, Very dark reddish brown (5YR2/4) when moist; dry; silty clay; strong medium angular blocky; hard; slightly sticky, plastic; many roots; common strongly weathered gravels; clear smooth boundary to
BAt	17-30	Reddish brown (5YR4/6) when dry, Dull reddish brown (5YR4/4) when moist; dry ; light clay; thin dull reddish brown (5YR4/4) cutan on ped surface; strong medium angular blocky, to firm; sticky, very plastic; many roots; many strongly weathered small pebbles; gradual irregular boundary to
Bt	30-60	Reddish brown (5YR4/8) when moist; moist; light clay; moderate coarse angular blocky; friable to firm; slightly sticky, plastic; common roots; many strongly weathered small pebbles; gradual smooth boundary to
BC	60-100	Reddish brown (5YR4/8); moist; light clay; weak coarse angular blocky; friable; sticky, plastic; common roots; common strongly weathered smalll pebbles; clear smooth boundary to
C	100-110+	Bright reddish brown (5YR5/8); moist; heavy clay;sticky, plastic; many roots; many strongly weathered cobbles

Location: T22
Topography: South 20^{o} east facing slope, gradient 21^{o}, on steep mountainous slope
Altitude 520m

Hor.	Depth (cm)	Description
Ap1	0-7	Dull orange (5YR6/3) when dry, Dark reddish brown (5YR3/3) when moist; dry; light clay; dominant structure is weak fine granular and subdominant one is weak medium angular blocky, slightly hard; sightly sticky, plastic; many roots; many strongly weathered gravels to pebbles; clear smooth boundary to
Ap2	7-18	Dull orange (5YR7/3) when dry, Dark reddish brown (5YR3/6) when moist; moderately dry; heavy clay; strong fine angular blocky; friable to firm when moist, slightly hard when dry; sticky, very plastic; common roots; abundant strongly weathered pebbles; clear wavy boundary to
BC	18-33	Bright reddish brown (5YR5/6) when dry, reddish brown (5YR4/8) when moist; moderately dry; heavy clay; strong fine angular blocky, friable to firm when moist, slightly hard when dry; sticky, very plastic; common roots; abundant strongly weathered cobbles; gradual smooth boundary to
R	33-85+	

Location: T23
Topography: South 28^{o} east facing graded slope, gradient 17^{o}, on the steep mountainous slope
Altitude: 537m

Hor.	Depth (cm)	Description
Ap	0-4	Dull orange (5YR6/3) when dry, Dark reddish brown (5YR3/3) when moist; dry; light clay; weak very fine angular blocky; slightly hard; slightly sticky, plastic; many roots; many strongly weathered gravels; clear smooth boundary to
BA	4-12	Dull reddish brown (2.5YR5/4) when dry, Dark reddish brown (5YR3/3); moderately dry; light clay ; strong medium angular blocky; slightly hard; sticky, very plastic; common roots; many strongly weathered pebbles; clear wavy boundary to
Bt	12-31	Bright brown (2.5YR5/6) when moist; moderately dry; heavy clay; thin faint dull reddish brown (2.5YR4/4) cutan on ped surface; moderate coarse subangular blocky, friable to firm when moist, slightly hard when dry; sticky, very plastic; common roots; many strongly weathered pebbles; clear wavy boundary to
C	31-46	Reddish brown (2.5YR4/6) when moist; moderately dry; heavy clay; no structure; sticky, very plastic; many roots; abundant strongly weathered pebbles; clear smooth boundary to
R	46-72	

Location: T24
Topography: South 28^{o} east facing slope, gradient 24^{o} on the steep mountainous slope
Altitude 544m

Hor.	Depth (cm)	Description
Ap	0-3	Very dark reddish brown (5YR2/3); moist; light clay; moderate fine to medium subangular blocky; friable; slightly sticky, plastic; many roots; few strongly weathered gravels; clear smooth boundary to
Bt	3-11	Dark reddish brown(5YR3/4); moist; clay loam; spot distinct dull reddish brown (5YR4/4) cutan on ped surface; moderate fine to medium subangular blocky; friable; slightly sticky, plastic; many roots; many strongly weathered small pebbles; clear smooth boundary to
BCt	11-25	Reddish brown (5YR4/6)*Dark reddish brown (10R3/3); dry; clay loam; spot distinct 2.5YR3/3 (dark reddish brown) cutan on ped surface; moderate coarse angular blocky; loose; slightly sticky, very plastic; common roots; abundant strongly weathered pebbles; clear wavy boundary to
R	25-67	

Location: T31
Topography: South 8^{o} west facing slope, gradient 14^{o} on the moderate steep montainous slope
Altitude: 511m

Hor.	Depth (cm)	Description
Ap	0-7	Very dark reddish brown (5YR2/3)*Dark reddish brown (5YR3/4); moist; light clay; weak medium subangular blocky; friable; slightly sticky, plastic; many roots; few strongly weathered pebbles; clear smooth boundary to
BAt1	7-28	Reddish brown (5YR4/6); moderately dry; heavy clay; thin dark reddish brown (5YR3/6) cutan on ped surface; moderate coarse subangular blocky; firm when moist, hard when dry; sticky, plastic; few roots; few strongly weathered gravels; gradual smooth boundary to
BAt2	28-59	Reddish brown (5YR4/6); moist; heavy clay; thin dull reddish brown (5YR4/4) cutan on ped surface; moderate coarse subangular blocky; firm when moist, hard when dry; sticky, plastic; common roots; common strongly weathered pebbles; clear smooth boundary to
Bt	59-100	Reddish brown (5YR4/8); moist; heavy clay; thin reddish brown cutan on ped surface (5YR4/6); moderate coarse angular blocky; firm; sticky, plastic; common roots; common strongly weathered pebbles

Location T32
Topography: South 20^{o} west facing slope, gradient 17^{o}, on the steep mountainous slope
Altitude: 515m

Hor.	Depth (cm)	Description
Ap	0-9	Dark reddish brown (5YR3/3); moist; light clay; moderate medium subangular blocky; friable; slightly sticky, plastic; many roots; common strongly weathered pebbles; clear smooth boundary to
Bt	9-20	Dull brown (7.5YR5/4) when dry, Dull reddish brown (5YR4/4) when moist; modrately dry; light clay; thin spot faint dark reddish brown (5YR3/3) cutan on ped surface; weak medium subangular blocky; very friable; slightly sticky, plastic; common roots; many strongly weathered pebbles; gradual smooth boundary to
CB	20-36	Bright reddish brown (5YR5/6) when dry, Dark reddish brown (2.5YR3/4) when moist; dry; heavy clay; sticky, very plastic; common roots; abundant strongly weathered pebbles; abrupt smooth boundary to
R	36-55+	

Location T33
Topography: South 22° west facing slope, gradient 16°, on the moderately steep mountainous slope
Altitude: 520m

Hor.	Depth (cm)	Description
Ap	0-5	Dark reddish brown (5YR3/3); moist; light clay; weak medium subangular blocky; very friable; slightly sticky, very plastic; many roots; common strongly weathered small pebbles; clear smooth boundary to
Bt	5-12	Dull reddish brown (5YR3/3) when dry, Dark reddish brown (5YR3/4) when moist; moderately dry; clay loam; distinct spot thin dark reddish brown (5YR3/3) cutan along a root channel or on ped surface; moderate medium angular blocky; friable; slightly sticky, plastic; many roots; many strongly weathered small pebble; clear smooth boundary to
CB	12-33	Dark reddish brown (5YR3/6); moist; light clay; no structure; sticky, very plastic; common roots; abundant strongly weathered pebbles; gradual smooth boundary to
R	33-75+	

Location: T41
Topography: North 86° west facing slope, gradient 9.5° on the moderately steep mountainous slope
Altitude: 512m

Hor.	Depth (cm)	Description
Ap	0-18	Dark brown (7.5YR3/3)*Brown (7.5YR4/4); moderately dry; heavy clay; no structure; sticky, plastic; many roots; few strongly weathered small pebbles; clear wavy boundary to
Bt1	18-43	Dull reddish brown (5YR4/4); moist; light clay; thin distinct continuous dull reddish brown (5YR4/3) cutan on ped surface; moderate coarse angular blocky; firm; slightly sticky, plastic; common roots; few strongly weathered gravels; gradual smooth boundary to
Bt2	43-85+	Reddish brown (5YR4/6); moist; heavy clay; thin faint dull reddish brown (5YR4/4) cutan on ped surface; moderate coarse angular blocky; firm; sticky, very plastic; few roots; no stone; gradual smooth boundary

Location: T42
Topography: North 19° west facing slope, gradient 16°, on the moderately steep mountainous slope
Altitude: 518m

Hor.	Depth (cm)	Description
Ap	0-29	Dull reddish brown (5YR4/4) when moist, brown (7.5YR4/4) when dry, other color is reddish brown (5YR4/6, distinct, many, coarse); moderately dry; clay loam; no structure; slightly sticky, plastic; many roots; many strongly weathered pebbles; clear wavy boundary to
R	29-78	Reddish brown (5YR4/8); moist; heavy clay; no structure; sticky, very plastic; few roots

Location: T43
Topography: North 72° west facing slope, gradient 8°, on the sloping mountainous slope
Altitude: 523m

Hor.	Depth (cm)	Description
Ap	0-27	Dark reddish brown (5YR3/3), other color is Reddish brown (5YR4/6, distinct, many, coarse); moderately dry; clay loam; no structure; slightly sticky, plastic; no root; abundant strongly weathered small pebbles; abrupt wavy boundary to
Bt	27-50	Reddish brown (5YR4/6); moist; heavy clay; thin continuous dull reddish brown (5YR4/4) cutan on ped surface; moderate coarse angular blocky; friable to firm; sticky, plastic; common roots; few strongly weathered gravels; gradual smooth boundary to
BC	50-66	Reddish brown (5YR4/6); moist; heavy clay; moderate coarse angular blocky; friable to firm; slightly sticky, plastic; few roots; few strongly weathered small pebbles; abrupt smooth boundary to
R	66-85+	

Appendix: Soil Profile Description

Location: F4 Tillage
Topography: South 86^{o} west facing slope, gradient 12^{o}, on the moderately steep mountainous slope
Altitude: 510m

Hor.	Depth (cm)	Description
Ap	0-23	Dull reddish brown (5YR4/4); dry; clay loam; moderate fine subangular blocky; hard to very hard; slightly sticky, plastic; many fine roots; gradual irregular boundary to
Bw	23-63	Reddish brown (5YR4/8); moderately dry; heavy clay; moderate fine subangular blocky; very firm; sticky, plastic; common very fine roots; clear regular boundary to
R	63-65+	

Location: F4 Non-tillage
Topography: South 84^{o} west facing slope, gradient 18^{o}, on steep mountainous slope
Altitude 510m

Hor.	Depth (cm)	Description
Ap	0-12?	Dark brown (7.5YR3/3); dry; clay loam; strong fine to medium angular blocky, hard; sightly sticky, plastic; common fine roots; clear smooth boundary to
BA	12-31	Dark reddish brown (5YR3/5); moderately dry; heavy clay; moderate fine to medium angular blocky; firm; sticky, plastic; few very fine roots; gradual smooth boundary to
Bw	31-70+	Dark reddish brown (5YR3/6); moist; heavy clay; moderate fine to medium angular blocky; firm; very sticky, very plastic; no root;

Location: T511
Topography: North 26^{o} west facing slope, gradient 11^{o} on the moderate steep mountainous slope
Altitude: 514m

Hor.	Depth (cm)	Description
A	0-6	Grayish brown (5YR4/2) when dry, Brownish brown (5YR2/2) when moist; moderately dry; light clay; weak fine subangular blocky; very friable; slightly sticky, very plastic; abundant roots; few strongly weathered gravels; clear smooth boundary to
AB	6-14	Dull reddish brown (5YR4/4); moist; heavy clay; thin dark reddish (5YUR3/3) on ped surface; strong medium subangular blocky; friable; slightly sticky, plastic; many roots; common strongly weathered gravels; clear smooth boundary to
BA	14-32	Reddish brown (5YR4/6); moist; heavy clay; moderately coarse angular blocky; friable; sticky, very plastic; many roots; few strongly weathered gravels; gradual smooth boundary to
Bt	32-72	Reddish brown (5YR4/8); moist; heavy clay; thin faint reddish brown (5YR4/6) cutan on ped surface; moderately coarse angular blocky; friable; sticky, very plastic; common roots; common strongly weathered small pebbles; clear smooth boundary to
BC	72-84+	Reddish brown (5YR4/8); moist; heavy clay; moderately medium subangular blocky; friable; sticky, very plastic; common roots; few strongly weathered gravels

Location: T512
Topography: North 16^{o} west facing slope, gradient 15^{o}, on the moderately steep mountainous slope
Altitude: 519m

Hor.	Depth (cm)	Description
A	0-2	Dark brown (7.5YR3/3); moderately dry; clay loam; weak fine subangular blocky; very friable; slightly sticky, plastic; many roots; many strongly weathered small pebbles; clear wavy boundary to
BA	2-27	Dull reddish brown (5YR4/4)*Brown (7.5YR4/6); moist; light clay; moderate medium to coarse angular blocky; very friable; sticky, plastic; many roots; many strongly weathered small pebbles; clear smooth boundary to
Bw	27-50	Reddish brown (5YR4/8); moist; heavy clay; moderate coarse angular blocky; friable; sticky, plastic; common roots; common strongly weathered small pebbles; clear smooth boundary to
BC	50-66	Reddish brown (5YR4/8); moist; heavy clay; weak coarse angular blocky; friable; sticky, plastic; common roots; many strongly weathered small pebbles; clear smooth boundary to
R	66-85+	

Location T513
Topography: North 5^{o} west facing slope, gradient 16.5^{o} on the moderate steep mountainous slope
Altitude: 524m

Hor.	Depth (cm)	Description
A	0-4	Dark brown (7.5YR3/3); moist; light clay; moderate fine subangular blocky; very friable; slightly sticky, plastic; abundant roots; few strongly weathered gravels;clear smooth boundary to
AB	4-11	Dull reddish brown (5YR4/4); moist; heavy clay; moderate medium to coarse subangular blocky; very friable; sticky, plastic; many roots; few strongly weathered gravels; clear smooth boundary to
BAt	11-35	Reddish brown (5YR4/8); moist; heavy clay; thin distinct cutan along a root channnel and on ped surface; moderate coarse angular blocky; friable; sticky, plastic; many roots; few strongly weathered gravels; gradual smooth boundary to
Bw	35-73	Bright reddish brown (5YR5/6); moist; heavy clay; strong coarse angular blocky; friable; sticky, plastic; common roots; few strongly weathered gravels; clear smooth boundary to
CB	73-85+	Reddish brown (5YR4/8); moist; heavy clay; no structure; sticky, very plastic; few roots; few strongly weathered pebbles

Location: T521
Topography: North 21^{o} east facing slope, gradient 18^{o}, on the steep mountainous slope
Altitude: 507m

Hor.	Depth (cm)	Description
A	0-6	Dark reddish brown (5YR3/3); moist; heavy clay; moderate fine to medium subangular blocky; very friable; slightly sticky, slightly plastic; many roots; common strongly weathered small pebbles; clear smooth boundary to
BA	6-20	Dark reddish brown (5YR3/6); moist; heavy clay; moderate medium subangular blocky; very friable; sticky, plastic; many roots; common strongly weathered small pebbles; clear smooth boundary to
Bw	20-53	Reddish brown (5YR4/8); moist; heavy clay; moderate coarse angular blocky; friable; sticky, very plastic; many roots; common strongly weathered pebbles; gradual smooth boundary to
BC	53-72	Reddish brown (5YR4/8); moist; heavy clay; weak coarse angular blocky; friable; sticky, very plastic; few roots; common strongly weathered pebbles; clear wavy boundary to
R	72-78	

Location: T522
Topography: North 1^{o} east facing slope, gradient 11^{o}, on the moderate steep mountainous slope
Altitude: 514m

Hor.	Depth (cm)	Description
A	0-7	Dark reddish brown (5YR3/3); moist; heavy clay; moderate medium subangular blocky; very friable; slightly sticky, plastic; abundant roots; few strongly weathered small pebbles; clear smooth boundary to
BA	7-23	Brown (7.5YR4/6) when dry, Dark reddish brown (5YR3/6) when moist; moderately dry; heavy clay; moderate medium angular blocky; friable to firm; sticky, very plastic; many roots; few strongly weathered small pebbles; gradual smooth boundary to
Bw	23-54	Reddish brown (5YR4/6); moist; heavy clay; moderate coarse angular blocky; friable to firm; sticky, plastic; common roots; few strongly weathered small pebbles; clear smooth boundary to
BC	54-88	Reddish brown (5YR4/6); moist; heavy clay; weak coarse angular blocky; friable to firm; sticky, plastic; few strongly weathered small pebbles; clear smooth boundary to
R	88-92+	

Location: T523
Topography: North 9^{o} west facing slope, gradinet 10^{o} on the moderate steep mountainous slope
Altitude: 517m

Hor.	Depth (cm)	Description
A	0-9	Dark reddish brown (5YR3/2); moist; light clay; moderate fine subangular blocky; friable; slightly stcky, plastic; abundant roots; few strongly weathered gravels; clear smooth boundary to
BAt	9-19	Dark reddish brown (5YR3/4); moist; light clay; thin spot dark reddish brown (5YR3/3) cutan on ped surface; moderate medium subangular blocky; friable; slightly sticky, plastic; many roots; few strongly weathered gravels; clear smooth boundary to
Bt	19-42	Reddish brown (5YR4/6); moist; heavy clay; thin faint continuous dull reddish brown (5YR4/4) cutan on ped surface; moderate coarse angular blocky; friable to firm; slightly sticky, very plastic; common roots; few strongly weathered gravels; gradual smooth boundary to
BC	42-60	Reddish brown (5YR4/8); moist; heavy clay; weak coarse angular blocky; firm; slightly sticky, very plastic; few roots; few strongly weathered gravels; abrupt smooth boundary to
R	60-73+	

Location: F61
Topography: North 70° west facing graded slope, gradient 21°, on the steep mountainous slope
Altitude: 506m

Hor.	Depth (cm)	Description

Ap 0-13 Grayish red (2.5YR6/2) with some dark reddish brown (2.5YR3/2); dry; clay loam; strong fine to medium subangular blocky; hard; slightly sticky, slightly plastic; common fine roots; few strongly weathered gravels; abrupt smooth boundary to

BAt 13-25 Dull reddish brown (2.5YR5/3); moderately dry; heavy clay ; thin dull reddish brown (2.5YR4/3) cutan on ped surface; strong fine to medium angular blocky; hard; sticky, plastic; common fine roots; common strongly weathered gravels and pebbles; gradual smooth boundary to

Bt 25-80+ Dull reddish brown (2.5YR4/5); moderately dry; heavy clay; thin dull reddish brown (2.5YR4/4) cutan on ped surface; strong fine to medium subangular blocky, friable ; sticky, plastic; few fine roots; abundant gravels;

Location: F62
Topography: North 32° west facing slope, gradient 16° on the moderately steep mountainous slope
Altitude 512m

Hor.	Depth (cm)	Description

Ap 0-3 Dark reddish brown (5YR3/3); dry; clay loam; thin cutan on ped surface; strong fine to medium subangular blocky; hard; sticky, very plastic; common fine roots; abrupt wavy boundary to

BAt 3-22 Dark reddish brown(2.5YR3/4); moist; heavy clay; thin cutan on ped surface; strong medium to coarse angular blocky; friable; very sticky, very plastic; common fine roots; gradual wavy boundary to

Bt 22-65 Dull reddish brown (2.5YR4/4); moist; heavy clay; thin cutan on ped surface; strong medium to coarse angular blocky; firm; very sticky, very plastic; few fine roots; few gravels and pebbles; diffuse smooth boundary to

R 65+

Location: F63
Topography: North 36° west facing slope, gradient 16° on the moderate steep montainous slope
Altitude: 516m

Hor.	Depth (cm)	Description

Ap 0-4 Grayish brown (5YR6/2) when dry, and dark reddish brown (5YR3/2) when moist; dry; clay loam; strong fine to medium subangular blocky; slightly hard; slightly sticky, plastic; many fine roots; abrupt smooth boundary to

BAt1 4-15 Dull reddish brown (2.5YR4/4); moderately dry; heavy clay; strong medium to coarse angular blocky; slightly hard; sticky, plastic; many fine roots; gradual smooth boundary to

BAt2 15-30 Dull reddish brown (2.5YR4/4); moist; heavy clay; thin cutan on ped surface; strong medium to coarse angular blocky; friable; sticky, plastic; common fine roots; few strongly weathered gravels; gradual smooth boundary to

Bt 30-55 Dull reddish brown (2.5YR4/4); moist; heavy clay; thin cutan on ped surface; moderate medium to coarse angular blocky; friable; sticky, plastic; common fine roots; few strongly weathered gravels; gradual smooth boundary to

R 55+

Appendix 2

Table Chemical properties of composite samples.

F[1]	L[2]	D[3]	P[4]	pHw	pHKCl	EC (mS)	Ex.Na	Ex.K	Ex.Ca	Ex.Mg	Ex.H	Ex.Al	Ex.NH_4	P_2O_5 (mg/100g)	Cl^-	NO_3^-	SO_4^{2-}	Total C (%)	Total N (%)	Moisture (%)
							(cmol(+)/Kg)								(cmol/Kg)					
2	1	1	1	6.31	5.57	96	0.075	0.87	5.82	1.93	0.14	0	0.10	3.91	0.236	0.015	0.032	2.595	0.219	2.814
			2	6.62	5.77	106	0.030	1.02	5.93	2.01	0.97	0	0.24	7.10	0.051	0.012	0.038	2.788	0.236	5.390
			3	7.16	6.48	150	0.108	0.76	7.78	1.88	0.18	0	0.16	11.00	0.034	0.036	0.008	2.501	0.201	6.599
		2	1	6.23	5.29	69	0.033	0.68	4.84	1.68	0.13	0	0.11	0.38	0.052	0.026	0.053	2.155	0.201	2.833
			2	6.41	5.19	62	0.021	0.75	4.35	1.38	0.92	0	0.17	0.38	0.055	0.001	0.007	2.068	0.193	4.266
			3	6.94	5.95	72	0.042	0.70	6.00	1.49	0.23	0	0.12	6.65	0.020	0.062	0.004	2.329	0.202	7.908
2	2	1	1	6.30	5.64	141	0.054	0.97	6.57	2.69	0.08	0	0.10	4.01	0.046	0.000	0.035	2.629	0.232	2.626
			2	6.71	5.80	127	0.035	0.74	6.49	2.25	0.78	0	0.17	4.77	0.041	0.010	0.029	2.884	0.296	3.360
			3	6.82	5.86	100	0.050	0.81	6.91	2.75	0.14	0	0.21	8.94	0.025	0.021	0.014	2.740	0.225	2.992
		2	1	6.18	5.29	78	0.051	0.59	4.84	1.83	0.14	0	0.09	2.58	0.034	0.001	0.016	1.932	0.189	2.531
			2	6.48	5.42	88	0.028	0.50	5.38	1.83	0.34	0	0.15	2.48	0.053	0.002	0.008	2.074	0.199	3.103
			3	6.62	5.49	53	0.066	0.49	4.60	1.83	0.21	0	0.19	4.77	0.019	0.048	0.011	2.165	0.204	9.653
2	3	1	1	6.53	5.86	160	0.061	1.10	6.36	3.29	0.13	0	0.12	8.25	0.275	0.013	0.026	2.979	0.237	2.308
			2	6.66	5.97	153	0.043	1.13	6.05	2.67	0.34	0	0.14	11.69	0.050	0.004	0.031	2.492	0.200	2.542
			3	6.07	5.43	80	0.051	0.90	6.65	2.82	0.16	0	0.17	12.15	0.033	0.034	0.011	2.408	0.195	3.917
		2	1	6.39	5.57	82	0.058	0.79	5.32	2.57	0.10	0	0.06	2.96	0.050	0.000	0.015	2.266	0.195	2.170
			2	6.58	5.42	71	0.050	0.85	4.69	2.20	0.25	0	0.17	4.11	0.061	0.000	0.017	2.187	0.190	3.397
			3	5.97	5.46	91	0.023	0.76	5.95	2.46	0.18	0	0.13	10.31	0.020	0.013	0.013	2.399	0.198	2.957
2	4	1	1	6.56	6.05	142	0.075	0.88	5.93	3.34	0.14	0	0.08	5.96	0.065	0.001	0.026	2.374	0.193	1.737
			2	7.35	6.92	410	0.060	1.09	7.77	2.65	0.15	0	0.10	40.33	0.078	0.034	0.032	2.804	0.208	1.980
			3	6.60	6.20	152	0.036	0.79	7.39	3.51	0.12	0	0.10	15.12	0.012	0.014	0.013	2.331	0.186	2.355
		2	1	6.36	5.62	85	0.040	0.66	3.81	2.41	0.14	0	0.06	0.00	0.031	0.000	0.008	1.446	0.135	1.488
			2	6.70	6.09	115	0.033	0.62	5.50	2.32	1.34	0	0.07	8.94	0.066	0.002	0.026	1.943	0.159	1.878
			3	6.52	5.79	69	0.032	0.55	5.08	2.71	0.16	0	0.12	3.63	0.027	0.012	0.007	1.502	0.137	3.385
3	1	1	1	6.39	5.76	150	0.045	0.75	7.02	2.58	0.10	0	0.11	4.11	0.029	0.015	0.020	3.055	0.266	2.562
			2	6.70	5.88	132	0.028	0.90	7.72	2.33	0.35	0	0.19	5.25	0.171	0.013	0.042	3.496	0.306	3.826
			3	6.18	5.67	91	0.031	0.45	7.87	2.14	0.16	0	0.18	6.19	0.020	0.051	0.009	2.773	0.244	6.853
		2	1	6.18	5.32	68	0.028	0.37	5.50	1.79	0.08	0	0.06	2.20	0.040	0.000	0.007	1.907	0.187	2.425
			2	6.42	5.42	85	0.037	0.51	5.93	1.66	0.22	0	0.17	1.91	0.043	0.006	0.021	2.263	0.218	5.260
			3	5.97	5.34	52	0.025	0.38	6.52	1.51	0.21	0	0.11	3.82	0.025	0.041	0.007	2.138	0.203	8.325
3	2	1	1	6.38	5.82	139	0.065	0.81	7.26	2.63	0.10	0	0.11	4.01	0.038	0.002	0.024	2.889	0.266	2.769
			2	6.59	6.03	226	0.037	0.98	9.23	2.40	0.25	0	0.15	10.08	0.036	0.021	0.042	3.667	0.321	3.368
			3	6.12	5.61	110	0.034	0.63	8.35	2.14	0.15	0	0.13	6.19	0.023	0.038	0.015	3.061	0.286	3.481
		2	1	6.23	5.46	70	0.030	0.52	6.42	2.04	0.13	0	0.07	0.48	0.047	0.000	0.013	2.322	0.235	2.548
			2	6.42	5.59	120	0.052	0.53	8.25	1.68	0.26	0	0.12	2.10	0.037	0.000	0.020	3.058	0.297	3.451
			3	6.03	5.37	72	0.019	0.48	6.82	1.67	0.15	0	0.04	3.34	0.018	0.130	0.009	2.336	0.231	10.546
3	3	1	1	6.28	5.64	115	0.073	0.78	6.40	1.93	0.13	0	0.09	4.11	0.035	0.001	0.014	2.818	0.241	2.560
			2	6.50	5.90	180	0.048	0.97	8.14	2.22	0.16	0	0.17	12.37	0.061	0.007	0.024	3.185	0.266	2.858
			3	5.76	5.07	68	0.023	0.42	5.30	1.59	0.19	0	0.14	3.44	0.020	0.106	0.010	3.209	0.300	8.591
		2	1	6.28	5.49	80	0.066	0.47	6.28	1.97	0.12	0	0.07	1.72	0.059	0.000	0.012	2.424	0.217	2.350
			2	6.39	5.54	120	0.034	0.63	7.53	1.93	0.20	0	0.11	10.77	0.048	0.002	0.017	3.578	0.290	2.905
			3	5.83	4.97	36	0.023	0.37	4.47	1.25	0.18	0	0.14	3.25	0.015	0.017	0.008	2.119	0.209	7.082
4	1	1	1	6.78	6.10	205	0.054	0.73	8.30	2.32	0.09	0	0.09	3.91	0.126	0.022	0.020	2.703	0.244	2.806
			2																	
			3	5.95	5.22	75	0.031	0.36	6.69	1.75	0.17	0	0.04	1.81	0.020	0.159	0.009	2.274	0.209	12.605
		2	1	6.38	5.59	89	0.037	0.42	7.41	2.24	0.14	0	0.09	0.00	0.031	0.001	0.012	2.432	0.219	3.037
			2																	
			3	6.21	5.33	64	0.030	0.35	6.87	2.14	0.14	0	0.13	1.72	0.017	0.070	0.005	2.097	0.199	9.803
4	2	1	1	5.84	4.99	80	0.043	0.86	5.05	2.20	0.15	0	0.15	0.00	0.024	0.043	0.021	2.436	0.214	2.564
			2																	
			3	5.63	4.54	28	0.026	0.55	3.38	1.07	0.31	0	0.12	2.20	0.012	0.014	0.013	1.816	0.171	6.543
		2	1	5.93	4.96	62	0.050	0.50	4.65	2.14	0.12	0	0.06	0.00	0.065	0.004	0.013	1.995	0.190	2.842
			2																	
			3	5.64	4.56	30	0.024	0.42	3.34	1.09	0.28	0	0.12	1.62	0.015	0.023	0.014	1.798	0.178	9.091
4	3	1	1	6.17	5.23	99	0.055	0.65	5.25	1.23	0.16	0	0.12	4.11	0.039	0.055	0.019	1.703	0.154	2.459
			2																	
			3	6.15	5.02	46	0.021	0.61	4.65	1.04	0.15	0	0.13	2.96	0.014	0.013	0.011	1.746	0.160	5.628
		2	1	6.45	5.32	97	0.050	0.47	5.88	1.09	0.12	0	0.06	0.67	0.029	0.020	0.013	1.833	0.163	2.523
			2																	
			3	6.34	5.12	55	0.025	0.52	4.86	1.15	0.14	0	0.14	2.67	0.024	0.015	0.011	1.767	0.164	7.045
5	1	1	1	5.92	5.02	76	0.056	0.69	3.19	1.77	0.13	0	0.09	1.53	0.037	0.000	0.024	3.726	0.277	3.545
			2	6.11	5.11	91	0.034	1.03	6.20	3.38	0.20	0	0.31	9.62	0.122	0.000	0.041	3.713	0.279	7.394
			3	6.06	4.93	75	0.048	1.02	4.82	3.09	0.22	0	0.22	6.65	0.022	0.018	0.024	3.596	0.268	5.304
		2	1	5.63	4.48	45	0.050	0.56	5.61	3.17	0.33	0.3	0.06	0.00	0.033	0.001	0.013	2.920	0.230	3.347
			2	5.83	4.58	31	0.036	0.71	3.97	1.69	0.88	0	0.26	1.91	0.068	0.003	0.016	2.241	0.203	10.466
			3	5.48	4.19	44	0.033	0.62	2.03	1.44	0.42	1.8	0.13	3.34	0.039	0.000	0.030	2.468	0.213	5.036
5	2	1	1	6.02	5.16	62	0.069	0.54	6.00	3.04	0.15	0	0.09	3.25	0.033	0.000	0.015	2.593	0.189	3.507
			2	6.45	5.22	74	0.028	0.76	5.37	2.64	0.21	0	0.34	3.72	0.050	0.001	0.024	3.169	0.240	9.399
			3	6.20	4.96	69	0.073	1.25	7.71	4.66	0.24	0	0.25	19.48	0.019	0.030	0.013	4.566	0.281	3.595
		2	1	5.87	4.77	37	0.078	0.42	3.07	2.00	0.23	0	0.06	0.00	0.039	0.003	0.008	2.439	0.200	3.171
			2	5.78	4.46	27	0.044	0.51	3.08	1.47	0.72	0	0.25	0.00	0.034	0.001	0.012	2.279	0.198	9.628
			3	5.94	4.56	61	0.061	0.65	3.69	2.73	0.24	0	0.31	5.50	0.025	0.048	0.054	2.525	0.214	5.881
5	3	1	1	6.08	5.09	69	0.111	0.74	4.87	3.06	0.20	0	0.10	2.01	0.030	0.000	0.014	3.439	0.266	3.916
			2	5.73	5.01	165	0.031	0.78	5.72	3.26	0.19	0	0.06	2.67	0.040	0.484	0.031	3.716	0.277	17.378
			3	6.85	5.61	120	0.051	1.55	8.28	4.56	0.17	0	0.25	9.40	0.049	0.056	0.013	3.718	0.290	7.014
		2	1	5.86	4.51	28	0.080	0.46	1.62	1.49	0.38	0.72	0.06	0.00	0.038	0.005	0.008	2.173	0.199	3.415
			2	6.05	4.90	54	0.045	0.67	4.15	2.11	0.30	0	0.20	1.34	0.050	0.045	0.014	2.533	0.218	6.263
			3	6.57	4.99	75	0.065	1.47	4.02	2.76	0.23	0	0.20	3.82	0.027	0.030	0.016	2.393	0.219	6.116

1) Field number: 1. 3rd years, 2: 4th years, 3: 9th years 4: 1st years. 2) Location number: 1. lower slope, 2. middle slope, 3. upper slope 3) Layer number: 1. 0-5 cm 2. 5-10 cm. 4) Period number: 1. before burning, 2. after burning, 3. after harvesting

Table Soil chemical properties before burning.

F[1]	L[2]	Lay[3]	pH H_2O	pH KCl	EC (mS)	Ex.Na	Ex.K	Ex.Ca	Ex.Mg	Ex.H	Ex.Al	Ex.NH_4	P_2O_5 (mg/100g)	Total C (%)	Total N (%)	Moisture (%)
						(cmol(+)/Kg)										
2	1	1	6.57	5.62	80	0.070	0.91	6.04	2.22	0.27	0.00	0.19	5.27	2.660	0.217	4.058
		2	6.51	5.23	47	0.092	0.52	3.76	1.33	0.07	0.00	0.14	1.81	1.591	0.153	6.615
		3	6.29	4.82	21	0.045	0.28	2.31	1.10	0.23	0.00	0.11	1.05	1.158	0.116	8.952
		5	6.28	4.66	14	0.039	0.20	1.38	1.12	0.30	0.24	0.08	0.86	0.983	0.093	10.180
		9	5.75	4.29	13	0.057	0.15	0.51	0.89	0.48	2.46	0.13	0.76	0.970	0.094	10.916
	2	1	6.30	5.22	77	0.050	0.69	4.04	2.34	0.25	0.00	0.12	7.10	2.660	0.215	3.320
		2	6.12	4.77	28	0.069	0.55	2.43	1.49	0.25	0.00	0.18	3.82	1.591	0.177	7.825
		3	6.23	4.89	31	0.066	0.63	2.71	1.54	0.20	0.00	0.13	2.67	1.158	0.183	10.045
	3	1	6.36	5.38	85	0.068	0.95	5.05	2.55	0.15	0.00	0.13	5.73	2.636	0.217	2.993
		2	6.30	4.67	17	0.052	0.28	1.54	1.96	0.29	0.00	0.11	1.24	1.142	0.177	8.812
		3	6.01	4.47	15	0.102	0.22	1.12	1.81	0.31	0.78	0.13	0.95	0.971	0.105	8.485
	4	1	6.61	5.96	120	0.080	0.70	4.99	3.64	0.06	0.00	0.07	8.71	2.399	0.183	2.228
		2	6.65	5.69	91	0.064	0.49	3.09	2.64	0.14	0.00	0.07	4.49	1.365	0.131	2.102
		3	6.57	5.47	58	0.048	0.41	1.96	2.34	0.12	0.00	0.05	2.01	0.850	0.085	1.613
3	1	1	6.10	4.91	48	0.104	0.35	4.12	1.60	0.09	1.50	0.21	3.91	2.235	0.218	5.695
		2	5.34	4.30	58	0.063	0.15	2.61	0.89	0.27	0.00	0.07	1.05	1.505	0.163	12.148
		3	5.77	4.46	23	0.099	0.15	3.05	0.99	0.25	0.60	0.14	1.24	1.264	0.135	6.491
		5	5.84	4.43	15	0.085	0.12	1.52	1.21	0.42	1.50	0.11	0.95	1.020	0.098	9.500
		4	6.14	4.67	15	0.119	0.11	2.79	1.20	0.16	0.36	0.05	0.57	1.139	0.112	7.481
	2	1	6.56	6.13	200	0.057	1.05	0.94	2.88	0.15	0.00	0.13	22.00	3.602	0.324	3.603
		2	6.38	5.62	108	0.039	0.72	6.89	1.45	0.10	0.00	0.12	5.96	2.324	0.231	2.579
		3	6.14	5.12	38	0.048	0.42	4.79	0.79	0.19	0.00	0.06	1.91	1.512	0.157	2.349
	3	1	6.52	5.72	104	0.050	0.63	6.38	2.26	0.18	0.00	0.26	5.77	2.723	0.238	1.834
		2	6.10	5.22	57	0.070	0.41	4.47	1.73	0.17	0.00	0.09	3.15	1.948	0.187	2.117
		3	5.87	4.73	30	0.046	0.38	2.56	1.04	0.34	0.00	0.07	2.48	1.379	0.139	2.376
4	1	1	6.27	5.46	96	0.061	0.59	7.40	2.73	0.25	0.00	0.09	2.48	2.384	0.223	3.066
		2	6.58	5.52	74	0.082	0.36	7.05	2.37	0.18	0.00	0.20	2.20	2.308	0.219	8.986
		3	6.37	5.28	60	0.056	0.33	6.04	2.11	0.17	0.00	0.07	1.15	1.679	0.171	3.506
		6	6.07	4.77	25	0.042	0.18	3.90	1.41	0.29	0.00	0.05	0.00	1.187	0.122	2.929
		7	5.93	4.50	23	0.048	0.18	3.21	1.30	0.24	0.90	0.11	0.00	1.148	0.114	8.755
	2	1	5.70	4.50	47	0.052	0.39	2.56	1.62	0.31	0.90	0.12	1.81	2.006	0.182	3.366
		2	5.97	4.87	49	0.055	0.36	5.05	2.30	0.27	0.00	0.12	1.72	2.602	0.219	4.068
		3	6.20	5.02	55	0.050	0.39	5.28	2.58	0.20	0.00	0.12	2.01	2.639	0.217	3.578
	3	1	6.16	5.12	74	0.044	0.96	3.50	1.94	0.20	0.00	0.11	4.11	1.767	0.164	0.109
		2	5.95	4.75	42	0.037	0.79	2.22	1.56	0.20	0.30	0.07	1.43	1.449	0.141	2.593
		3	6.30	5.20	57	0.043	0.77	5.19	2.09	0.22	0.00	0.08	2.67	2.157	0.179	2.817
		5	5.28	4.34	16	0.073	0.39	1.33	0.87	0.51	4.80	0.05	0.95	0.648	0.073	3.369
		9	5.13	4.26	19	0.057	0.25	1.29	0.92	0.45	6.12	0.03	0.86	0.505	0.067	2.760
5	1	1	5.96	4.65	36	0.050	0.61	3.66	2.16	0.13	0.96	0.14	4.81	3.219	0.212	4.890
		2	5.64	4.33	19	0.038	0.27	1.16	1.11	0.46	2.52	0.05	1.05	1.734	0.150	3.414
		3	5.57	4.21	12	0.042	0.19	0.33	0.96	0.46	4.86	0.03	0.95	1.304	0.123	2.840
	2	1	6.17	5.18	60	0.061	0.60	5.37	2.58	0.19	0.24	0.12	4.86	2.893	0.217	3.621
		2	5.64	4.34	20	0.041	0.63	1.41	1.17	0.69	1.80	0.06	0.00	1.434	0.138	3.437
		3	5.36	4.23	10	0.032	0.35	0.56	0.47	1.05	4.56	0.03	0.86	0.948	0.093	3.076
		9	5.22	4.23	7	0.033	0.15	0.26	0.19	0.82	6.54	0.11	8.25	0.452	0.063	3.173
		8	5.31	4.22	14	0.050	0.23	0.36	0.30	0.90	5.70	0.04	0.76	0.675	0.074	2.731
	3	1	6.59	5.52	116	0.031	1.25	5.91	3.14	0.22	0.00	0.26	3.82	3.402	0.281	4.762
		2	6.25	5.01	61	0.045	1.21	2.95	2.00	0.29	0.00	0.15	1.91	2.075	0.188	4.136
		3	5.84	4.43	18	0.049	0.45	0.90	1.43	0.46	1.44	0.04	0.86	1.194	0.116	3.133
		9	5.50	4.28	10	0.031	0.27	0.74	0.79	0.44	4.80	0.03	0.57	0.633	0.075	3.452
6	1	1	5.97	4.86	56	0.034	0.49	5.30	2.63	0.24	0.00	0.15	3.91	4.464	0.276	5.122
		2	5.61	4.24	25	0.036	0.18	1.47	1.04	0.63	2.52	0.07	1.24	2.726	0.164	4.467
		3	5.62	4.17	13	0.026	0.15	0.64	0.90	0.78	4.20	0.06	0.86	1.530	0.115	4.859
		5	5.45	4.17	12	0.054	0.11	0.93	0.57	0.82	6.00	0.05	0.48	0.952	0.093	5.652
	2	1	6.09	4.91	55	0.047	0.66	4.21	2.46	0.29	0.00	0.13	4.77	3.036	0.226	4.520
		2	5.34	4.12	19	0.048	0.51	1.04	0.72	0.77	6.60	0.07	1.72	1.595	0.139	4.249
		3	5.21	4.05	14	0.039	0.30	0.55	0.36	0.88	1.92	0.04	0.76	1.114	0.104	4.101
	3	1	5.83	4.42	40	0.069	0.54	2.34	2.69	0.55	0.48	0.25	4.77	3.516	0.247	7.687
		2	5.38	4.04	19	0.030	0.23	0.91	0.92	0.72	6.60	0.19	1.62	1.594	0.148	5.611
		3	5.35	4.09	10	0.023	0.20	0.46	0.32	0.86	7.86	0.06	1.15	1.179	0.110	5.092
		8	5.19	4.16	9	0.033	0.19	0.71	0.66	0.78	8.94	0.03	0.67	0.597	0.071	5.030

1) Field number 2: 3rd year, 3: 4th year 4: 9th year, 5 and 6: 1st year
2) Location number 1: lower slope, 2: middle slope, 3: upper slope
3) Horizon depth 1: 0-10 cm, 2: 10-20 cm, 3: 20-30 cm

Table Soil physical properties.

F[1]	L[2]	Lay[3]	HC[4] (mm/hr)	BD[5] (g/cc)	SOLID	WATER	AIR	31.6 kpa	100 kpa	316 kpa	501 kpa	1000 kpa	1580 kpa	CS (%)	FS (%)	SILT (%)	CLAY (%)
					(%)			MOISTURE CONTENT AT DIFFERENT SUCTION (%)									
2	1	1	295	0.99	37.3	11.1	51.6	34.0	32.7	30.5	29.2	26.8	25.8	10.0	16.8	26.6	46.6
		2	77	1.32	49.8	24.4	25.8	37.9	36.7	35.0	33.6	32.3	31.9	9.7	15.6	22.4	52.3
		3	61	1.33	50.2	27.1	22.7	37.4	36.4	34.7	33.8	32.7	32.4	8.2	14.2	22.0	55.6
		5	346	1.37	37.9	28.2	33.9	37.9	37.1	35.0	34.3	33.1	32.8	8.4	11.1	24.4	56.1
		9	1235	1.23	46.4	28.1	25.5	37.1	36.0	34.1	32.7	31.6	31.1	5.8	10.9	31.2	52.1
	2	1	232	1.11	35.9	3.5	60.6	33.8	32.6	30.8	28.9	27.6	27.1	12.5	13.2	27.1	47.3
		2	185	0.95	36.1	12.3	51.6	30.3	28.8	26.6	25.5	24.3	23.6	12.0	13.0	26.7	48.3
		3	.	.	.	.	.	.	.	.	.	.	.	11.9	12.3	26.0	49.7
	3	1	95	1.15	43.3	5.6	51.1	38.4	36.5	34.2	31.9	30.4	29.1	10.3	20.0	25.2	44.5
		2	42	1.41	53.1	14.5	32.4	38.0	36.2	34.1	32.5	30.8	29.9	13.5	16.7	22.5	47.4
		3	11	1.46	55.0	15.0	30.0	36.5	35.6	33.8	32.9	32.7	29.7	16.4	15.9	20.4	47.4
	4	1	61	1.18	44.3	20.9	34.8	32.3	31.1	28.7	27.6	25.9	24.7	12.4	28.6	23.1	36.1
		2	100	1.34	50.2	15.0	34.8	31.4	29.5	27.4	25.9	24.2	23.7	14.2	28.7	21.9	35.3
		3	370	1.15	43.4	32.0	24.7	39.2	37.6	34.8	33.6	32.2	31.1	12.5	25.8	25.0	36.7
3	1	1	285	1.23	46.2	23.1	30.7	36.4	35.3	33.3	32.3	30.9	29.9	7.2	17.5	27.0	48.3
		2	77	1.29	48.7	21.3	30.0	37.5	36.2	34.0	32.9	31.4	30.6	7.2	16.1	32.0	44.7
		3	22	1.43	53.8	26.4	19.8	39.1	37.9	36.1	35.1	33.9	33.7	6.6	16.0	26.0	51.4
		5	2	1.42	53.5	29.1	17.3	39.2	38.2	36.1	35.4	34.3	33.9	7.2	14.9	23.6	54.3
		4	1	1.53	57.8	27.5	14.7	39.0	37.0	36.0	35.2	34.1	29.2	8.2	14.9	23.5	53.5
	2	1	232	0.94	49.2	15.6	35.2	35.3	33.0	31.0	29.1	27.7	27.1	12.6	16.5	24.4	46.5
		2	68	1.36	51.2	17.0	31.8	37.9	36.3	33.3	32.2	30.7	29.6	15.7	15.4	23.3	45.6
		3	.	.	.	.	.	.	.	.	.	.	.	15.1	14.8	23.5	46.7
	3	1	142	1.01	38.2	13.6	48.2	30.7	29.2	27.3	25.6	24.2	23.8	13.8	26.3	22.4	37.6
		2	.	.	.	.	.	.	.	.	.	.	.	14.4	24.3	24.6	36.8
		3	.	.	.	.	.	.	.	.	.	.	.	13.9	22.6	26.1	37.4
4	1	1	393	0.98	36.9	18.6	44.5	31.3	30.0	27.7	26.5	25.1	24.6	7.9	13.5	29.6	49.0
		2	1179	1.06	40.2	25.1	34.7	33.5	32.4	30.3	29.2	27.8	27.3	8.1	13.1	27.7	51.1
		3	708	0.97	36.5	22.3	41.2	30.2	29.2	27.3	26.6	25.2	24.4	8.3	13.1	28.5	50.2
		6	58	1.34	50.5	27.4	22.1	37.8	36.6	34.7	33.8	32.4	31.9	7.1	12.1	22.2	58.6
		7	221	,1.26	47.3	26.3	26.4	35.8	34.7	32.7	31.8	30.6	30.1	6.8	12.1	26.2	54.9
	2	1	884	1.05	39.0	28.7	32.3	32.3	30.8	28.9	28.0	26.8	26.4	10.1	9.8	23.9	56.3
		2	442	0.95	35.8	18.1	46.1	31.7	30.0	28.5	27.2	25.8	25.6	9.7	10.8	26.1	53.4
		3	354	1.01	38.0	20.9	41.2	33.7	32.3	30.0	29.0	27.7	26.7	9.8	11.2	23.8	55.2
	3	1	442	1.13	42.7	26.6	30.8	33.2	31.7	29.8	28.7	27.6	27.1	13.3	14.7	26.5	45.6
		2	442	1.08	40.6	20.6	38.9	31.6	30.4	28.5	27.6	26.4	25.7	12.9	14.4	26.0	46.8
		3	442	1.03	38.9	20.4	40.8	32.5	30.8	28.5	27.1	26.3	24.7	12.7	13.2	26.6	47.5
		5	442	1.36	51.4	35.6	13.0	42.7	41.2	39.3	38.5	37.9	37.0	7.2	8.2	20.2	64.4
		9	10	1.37	51.8	35.5	12.7	41.2	39.8	38.3	37.7	37.1	35.2	12.8	8.6	18.2	60.4
5	1	1	353	1.04	39.3	36.7	24.0	41.0	38.6	36.5	35.3	33.6	32.0	8.1	12.3	22.9	56.8
		2	345	1.16	43.7	38.9	17.4	41.0	39.3	37.3	36.3	35.3	32.7	7.3	9.8	27.5	55.5
		3	140	1.28	48.2	27.4	24.5	31.9	29.8	28.0	27.0	26.2	23.8	5.9	8.5	22.5	62.8
	2	1	211	1.17	44.0	33.4	22.6	40.0	37.6	35.0	33.7	32.6	31.0	10.5	15.2	26.4	47.8
		2	223	1.24	46.7	31.0	22.4	39.8	37.8	35.2	34.0	33.1	32.0	8.2	14.0	21.7	56.1
		3	20	1.32	49.6	30.4	20.0	41.4	39.3	36.9	35.9	35.1	34.0	8.2	10.3	23.8	57.7
		9	.	.	.	.	.	.	.	.	.	.	.	8.8	9.3	22.9	59.0
		8	.	.	.	.	.	.	.	.	.	.	.	8.8	12.4	22.9	55.9
	3	1	.	.	.	.	.	.	.	.	.	.	.	11.5	16.8	26.0	45.7
		2	632	1.12	42.0	29.4	28.6	35.3	33.6	31.7	30.9	29.8	29.5	12.6	15.7	25.2	46.5
		3	345	1.25	47.2	31.8	21.1	37.3	35.9	34.2	33.3	32.5	32.0	9.8	12.6	24.1	53.6
		9	68	1.32	49.7	32.4	17.9	42.4	40.6	38.7	37.9	37.3	36.5	10.0	10.8	19.1	60.2
6	1	1	.	.	.	.	.	.	.	.	.	.	.	7.3	14.4	21.8	56.5
		2	29	1.18	44.6	32.6	22.8	39.2	37.3	35.1	34.0	33.1	32.6	5.9	12.7	23.9	57.5
		3	.	.	.	.	.	.	.	.	.	.	.	5.0	10.6	21.0	63.5
		5	.	.	.	.	.	.	.	.	.	.	.	4.9	10.5	16.5	68.1
	2	1	.	.	.	.	.	.	.	.	.	.	.	9.2	14.2	23.5	53.1
		2	.	.	.	.	.	.	.	.	.	.	.	7.8	12.6	20.6	59.1
		3	.	.	.	.	.	.	.	.	.	.	.	9.5	11.4	25.9	53.3
	3	1	.	.	.	.	.	.	.	.	.	.	.	6.8	14.6	22.3	56.3
		2	.	.	.	.	.	.	.	.	.	.	.	5.1	12.2	22.1	60.5
		3	.	.	.	.	.	.	.	.	.	.	.	5.2	9.6	22.3	62.9
		8	.	.	.	.	.	.	.	.	.	.	.	6.2	9.8	14.5	69.6

1) Field number: 2. 3rd year, 3. 4th year, 4. 9th year, 5 and 6 1st year
2) Location number: 1. lower slope, 2. middle slope, 3. upper slope
3) Horizon number: 1. 0-10 cm, 2. 10-20 cm, 3. 20-30 cm
4) Hydraulic conductivity, 5) Bulk density

F2		Dry matter of maize plant in each field dry	F.W	plant.No	F.W/plant	H2Orate	perplant dry weigh	Average /5plant	Plant.No /25m2	D.Mton/ha	D.Ston/ha	Plant.No /ha
L-1-1		98.02	300	1	300	0.326733	300	180.405	78	13.01838	2.522988	31200
	2	411.97	1100	2	550	0.374518	205.985					
	3	213.88	550	1	550	0.388872	213.88					
	4	182.09	550	2	275	0.331072	91.045					
	5	182.23	550	2	275	0.331327	91.115					
C-1-1		256.18	750	2	375	0.341573	128.09	197.742	61	15.64075	2.87244	24400
	2	176.69	650	1	650	0.271830	176.69					
	3	133.4	500	1	500	0.2668	133.4					
	4	502.58	1400	2	700	0.358985	251.29					
	5	299.24	900	1	900	0.332488	299.24					
R-1-1		225.74	700	2	350	0.322485	112.87	207.4145	95	17.20830	3.529642	38000
	2	581.74	1300	1	1300	0.447492	581.74					
	3	172.34	600	2	300	0.287233	86.17					
	4	517.41	1600	4	400	0.323381	129.3525					
	5	253.88	800	2	400	0.31735	126.94					
L-2-1		172.68	400	1	400	0.4317	172.68	148.8746	67	8.865466	2.411226	26800
	2	268.78	700	1	700	0.383971	268.78					
	3	210.82	700	3	233	0.301171	70.27333					
	4	163.3	600	2	300	0.272166	81.65					
	5	301.98	800	2	400	0.377475	150.99					
C-2-1		219.38	600	4	150	0.365633	54.845	108.907	79	4.744293	1.507174	31600
	2	102.1	250	1	250	0.4084	102.1					
	3	173.52	500	1	500	0.34704	173.52					
	4	191.44	550	2	275	0.348072	95.72					
	5	236.7	800	2	400	0.295875	118.35					
R-2-1		206.39	800	1	800	0.257987	206.39	94.01	80	3.535152	2.654848	32000
	2	109.11	400	2	200	0.272775	54.555					
	3	84.74	300	1	300	0.282466	84.74					
	4	147.29	400	2	200	0.368225	73.645					
	5	202.88	650	4	163	0.312123	50.72					
L-3-1		256.99	800	2	400	0.321237	128.495	102.9343	60	4.238190	1.922218	24000
	2	140.89	500	1	500	0.28178	140.89					
	3	110.72	450	1	450	0.246044	110.72					
	4	159.2	500	2	250	0.3184	79.6					
	5	164.9	650	3	216	0.253692	54.96666					
C-3-1		143	550	2	275	0.26	71.5	113.561	99	5.158440	1.244208	39500
	2	222.77	750	1	750	0.297026	222.77					
	3	196.18	700	2	350	0.280257	98.09					
	4	199.45	700	2	350	0.284928	99.725					
	5	227.16	800	3	266.6666	0.28395	75.72					
R-3-1		111.9	300	1	300	0.373	111.9	131.516	75	6.918583	2.23993	30000
	2	222.21	700	1	700	0.317442	222.21					
	3	241.23	850	2	425	0.2838	120.615					
	4	232.85	900	2	450	0.258722	116.425					
	5	259.29	900	3	300	0.2881	86.43					
L-4-1		189.96	750	2	375	0.25328	94.98	127.577	62	6.510356	1.370442	24800
	2	171.59	700	2	350	0.245128	85.795					
	3	252.08	1000	2	500	0.25208	126.04					
	4	160.94	750	1	750	0.214586	160.94					
	5	170.13	600	1	600	0.28355	170.13					
C-4-1		205.21	700	2	350	0.293157	102.605	100.039	47	4.003120	1.217221	18800
	2	164.13	450	1	450	0.364733	164.13					
	3	155.71	700	2	350	0.222442	77.855					
	4	87.16	300	2	150	0.290533	43.58					
	5	224.05	650	2	325	0.344692	112.025					
R-4-1		258.93	900	3	300	0.2877	86.31	149.0116	69	8.881790	1.382386	27600
	2	288.16	1050	3	350	0.274438	96.05333					
	3	170.39	700	1	700	0.243414	170.39					
	4	227.29	850	1	850	0.2674	227.29					
	5	330.03	1000	2	500	0.33003	165.015					
F3												
L-1-1		120.85	400	1	400	0.302125	120.85	105.3946	122	4.443214	3.547786	48800
	2	194.51	750	2	375	0.259346	97.255					
	3	259.03	700	3	233	0.370042	86.34333					
	4	120.91	450	1	450	0.268688	120.91					
	5	203.23	750	2	375	0.270973	101.615					
C-1-1		202.8	700	2	350	0.289714	101.4	124.2193	122	6.172177	3.29561	48800
	2	294.98	750	3	250	0.393306	98.32666					
	3	128.42	400	1	400	0.32105	128.42					
	4	174.93	500	1	500	0.34986	174.93					
	5	236.04	650	2	325	0.363138	118.02					
R-1-1		181.86	600	1	600	0.3031	181.86	174.556	81	12.20188	2.934264	32400
	2	227	700	1	700	0.324285	227					
	3	219.02	1000	2	500	0.21902	109.51					
	4	238.26	700	1	700	0.340371	238.26					
	5	233.3	700	2	350	0.333285	116.65					
L-2-1		142.93	500	1	500	0.28586	142.93	95.61666	158	3.657018	3.646986	63200
	2	116.73	350	2	175	0.333514	58.365					
	3	102.74	350	1	350	0.293542	102.74					
	4	235.75	750	3	250	0.314333	78.58333					
	5	190.93	600	2	300	0.318216	95.465					
C-2-1		176.14	500	1	500	0.35228	176.14	132.0333	98	6.973120	3.601416	39200
	2	198.58	600	2	300	0.330966	99.29					
	3	510.68	1250	3	417	0.408544	170.2266					
	4	264.26	650	2	325	0.406553	132.13					
	5	164.76	550	2	275	0.299563	82.38					
R-2-1		253.87	750	2	375	0.338493	126.935	128.545	70	6.609526	2.993866	28000
	2	164.13	600	1	600	0.27355	164.13					
	3	345.32	1200	3	400	0.287766	115.1066					
	4	376.03	900	3	300	0.417811	125.3433					
	5	222.42	750	2	375	0.29556	111.21					
L-3-1		221.86	650	3	217	0.341323	73.95333	104.0393	111	4.329673	3.782	44400
	2	146.63	500	1	500	0.29326	146.63					
	3	214.37	600	2	300	0.357283	107.185					
	4	113.71	300	2	150	0.379033	56.855					
	5	406.72	1300	3	433	0.312861	135.5733					
C-3-1		185.35	550	3	183	0.337	51.78333	134.6246	91	7.249520	4.122589	36400
	2	182.61	500	3	167	0.36522	60.87					
	3	181.07	600	1	600	0.301783	181.07					
	4	181.81	650	1	650	0.279707	181.81					
	5	187.59	700	1	700	0.267985	187.59					
R-3-1		426.19	1050	1	1050	0.405895	426.19	225.683	92	20.37312	2.776258	36800
	2	190.4	500	1	500	0.3808	190.4					
	3	369.46	1050	2	525	0.351866	184.73					
	4	323.17	900	2	450	0.359077	161.585					
	5	165.51	600	1	600	0.27585	165.51					

		Dry matter of maize plant in each field dry	F.W	plant.No	F.W/plant	H2Orate	perplant dry weigh	Average /5plant	Plant.No /25m2	D.Mton/ha	D.Ston/ha	Plant.No /ha
F4												
L-1-1		307.71	950	1	950	0.323905	307.71	147.565	83	8.710171	2.859733	33200
	2	178.03	650	2	325	0.273892	89.015					
	3	164.49	500	1	500	0.32898	164.49					
	4	162.09	650	3	217	0.249369	54.03					
	5	245.16	750	2	375	0.32688	122.58					
C-1-1		558.68	1500	3	500	0.372453	186.2266	212.8133	81	18.11580	3.513994	32400
	2	246.27	700	1	700	0.351814	246.27					
	3	281.82	950	1	950	0.296652	281.82					
	4	393.96	1100	2	550	0.358145	196.98					
	5	305.54	1000	2	500	0.30554	152.77					
R-1-1		222.28	850	2	425	0.261505	111.14	98.43633	67	3.875884	3.160072	26800
	2	285.98	1200	2	600	0.238316	142.99					
	3	336.96	1050	3	350	0.320914	112.32					
	4	157.53	450	2	225	0.350066	78.765					
	5	140.5	650	3	217	0.216769	46.36666					
L-2-1		258.33	750	1	750	0.34444	258.33	172.7016	121	11.93034	4.60928	48400
	2	172.18	600	2	300	0.286966	86.09					
	3	520.38	1750	2	875	0.29736	260.19					
	4	323.53	1150	3	383	0.281330	107.8433					
	5	302.11	900	2	450	0.335677	151.055					
C-2-1		172.95	550	2	275	0.314454	86.475	84.31283	107	2.843461	3.012808	42800
	2	89.02	250	2	125	0.35608	44.51					
	3	228.38	700	3	233	0.326257	76.12666					
	4	282.13	800	4	200	0.352662	70.5325					
	5	143.92	500	1	500	0.28784	143.92					
R-2-1		151.78	500	3	167	0.30356	50.59333	77.659	127	2.412368	3.273984	50800
	2	89.9	300	1	300	0.299666	89.9					
	3	182.72	450	3	150	0.406044	60.90666					
	4	186.23	550	2	275	0.3386	93.115					
	5	187.56	500	2	250	0.37512	93.78					
L-3-1		486.07	1450	3	483	0.335220	162.0233	168.9066	113	11.41178	4.541068	45200
	2	238.14	900	1	900	0.2646	238.14					
	3	222.08	750	3	250	0.296106	74.02666					
	4	520.78	1550	3	517	0.335987	173.5933					
	5	393.5	1300	2	650	0.302692	196.75					
C-3-1		268.67	850	4	213	0.316082	67.1675	129.6575	113	6.724426	3.6784	45200
	2	149.48	700	1	700	0.213542	149.48					
	3	243.39	800	2	400	0.304237	121.695					
	4	287.82	600	3	200	0.4797	95.94					
	5	428.01	1100	2	550	0.3891	214.005					
R-3-1		152.18	450	1	450	0.338177	152.18	120.743	153	5.831548	4.265908	61200
	2	444.81	1050	3	350	0.423628	148.27					
	3	210.07	550	2	275	0.381945	105.035					
	4	283.89	900	3	300	0.315433	94.63					
	5	103.6	350	1	350	0.296	103.6					
F5												
NT-L1		125.6	400	1	400	0.314	125.6	158.8666	22	2.911390	2.10792	18326
	2	259.33	700	1	700	0.370471	259.33					
	3	91.67	300	1	300	0.305566	91.67					
M-1			200	1	200				65		1.462724	30940
	2		200	1	200							
	3		150	1	150							
U-1		135.09	500	1	500	0.27018	135.09	140.507	78	4.570130	2.38374	32526
	2	121.36	550	2	275	0.220654	60.68					
	3	299.07	850	2	425	0.351847	149.535					
	4	109.12	400	1	400	0.2728	109.12					
	5	248.11	650	1	650	0.381707	248.11					
TT-L1		181.84	550	1	550	0.330618	181.84	144.667	95	8.371416	4.502186	38000
	2	167.1	500	1	500	0.3342	167.1					
	3	110.25	450	1	450	0.245	110.25					
	4	189.11	700	2	350	0.270157	94.555					
	5	339.18	1100	2	550	0.308345	169.59					
M-1			450	1	450							
	2	192.26	350	1	350	0.549314	192.26	192.26	141		4.109847	50337
	3		700	1	700							
	4		350	1	350							
	5		750	1	750							
U-1		215.88	550	1	550	0.392509	215.88	266.468	110	10.46419	3.83824	44000
	2	321.84	600	1	600	0.5364	321.84					
	3	328.87	1150	1	1150	0.285973	328.87					
	4	229.86	700	1	700	0.328371	229.86					
	5	235.89	600	1	600	0.39315	235.89					

L:left side, C:Center, R:Right side in fields
1 or L:lower, 2 or M:Middle, 3 or U:Middle 2 in F2 or Upper in F3, F4, F5. 4:Upper in F2
NT: no-tillage T:tractor tillage

Table Weed biomass in each location

		WEED BIOMASS DATA [Under maize cropping]					
F2	/25m2	control	Kg/m2	control	ton/ha		
L1	2	7.5	0.5	1.875	5	2.225	0.55625
L2	3		0.75		7.5		
L3	1.35		0.3375		3.375		
L4	2.55		0.6375		6.375		
C1	0.65		0.1625		1.625	1.2875	0.321875
C2	2.25		0.5625		5.625		
C3	1.25		0.3125		3.125		
C4	1		0.25		2.5		
R1	1.15		0.2875		2.875	1.0375	0.259375
R2	1.25		0.3125		3.125		
R3	0.7		0.175		1.75		
R4	1.05		0.2625		2.625		
F3							
L1	0.95	2.5	0.2375	0.625	2.375	0.55	0.183333
L2	0.65		0.1625		1.625		
L3	0.6		0.15		1.5		
C1	0.25		0.0625		0.625	0.3	0.1
C2	0.5		0.125		1.25		
C3	0.45		0.1125		1.125		
R1	1.15		0.2875		2.875	0.65	0.216666
R2	0.85		0.2125		2.125		
R3	0.6		0.15		1.5		
F4							
L1	0.65	0.95	0.1625	0.2375	1.625	0.625	0.208333
L2	1.1		0.275		2.75		
L3	0.75		0.1875		1.875		
C1	0.75		0.1875		1.875	0.4375	0.145833
C2	0.4		0.1		1		
C3	0.6		0.15		1.5		
R1	0.6		0.15		1.5	0.575	0.191666
R2	0.95		0.2375		2.375		
R3	0.75		0.1875		1.875		
F5							
NT-L	1.35		0.3375		3.375	0.5625	0.1875
NT-M	0.6	16.25	0.15	4.0625	1.5		
NT-U	0.3		0.075		0.75		
T-L	0.4		0.1		1	0.475	0.158333
T-M	0.65		0.1625		1.625		
T-U	0.85		0.2125		2.125		

L:left side, C:Center, R:Right side in fields
1 or L:lower, 2 or M:Middle, 3 or U:Middle 2 in F2 or Upper in F3, F4, F5. 4:Upper in F2
NT: no-tillage T:tractor tillage

Table Root biomass in each layer

		Root<1 mm[g]				[ton/ha]		
		[0-10]cm	[10-20]cm	[20-30]cm	[0-10]cm	[10-20]cm	[20-30]cm	[0-30]
F2-1		50.28	2.93	5.71	5.586108	3.25523	6.34381	65.46012
	1	16.89	6.75	2.26	1.876479	7.49925	2.51086	28.7749
	2	34.21	5.76	3.45	3.800731	6.39936	3.83295	48.23962
	2	46.82	1.52	0.53	5.201702	1.68872	0.58883	54.29457
	3	10.23	2.75	1.73	1.136553	3.05525	1.92203	16.34281
	3	15.85			1.760935	0	0	17.60935
	4	64.13	5.28	2.43	7.124843	5.86608	2.69973	79.81424
	4	16.28	9.85	4.14	1.808708	10.94335	4.59954	33.62997
F3-1		10.72	0.63	3.78	1.190992	0.69993	4.19958	16.80943
	1	16.16	2.66	0.43	1.795376	2.95526	0.47773	21.38675
	2	6.67	5.9	8.62	0.741037	6.5549	9.57682	23.54209
	2	7.44	2.81	1.26	0.826584	3.12191	1.39986	12.78761
	3	14.35	2.06	1.88	1.594285	2.28866	2.08868	20.32019
	3	16.13	5.11	2.34	1.792043	5.67721	2.59974	26.19738
F4-1		5	0.68	12.77	0.5555	0.75548	14.18747	20.49795
	1	10.81	17.29	2.28	1.200991	19.20919	2.53308	33.75218
	2	5	4.38	1.42	0.5555	4.86618	1.57762	11.9988
	2	3.31	2.47	2.7	0.367741	2.74417	2.9997	9.42128
	3	5.96	5.94	4.47	0.662156	6.59934	4.96617	18.18707
	3	6.4	2.5	0.48	0.71104	2.7775	0.53328	10.42118
F5-1		34.04	2.56	0.46	3.781844	2.84416	0.51106	41.17366
	1	29.32	2.53	2.36	3.257452	2.81083	2.62196	38.00731
	2	34.8	10.15	3.18	3.86628	11.27665	3.53298	53.47243
	2	41.3	2.48	4.97	4.58843	2.75528	5.52167	54.16125
	3	33.11	7.67	3.89	3.678521	8.52137	4.32179	49.62837
	3	42.9	10.12	1.62	4.76619	11.24332	1.79982	60.70504
Average		10	20	30	10	20	30	all
F2		31.83625	4.355	2.53125	3.537007	4.838405	2.812218	43.02069
F3		11.91166	3.195	3.051666	1.323386	3.549645	3.390401	20.17390
F4		6.08	5.543333	4.02	0.675488	6.158643	4.46622	17.37974
F5		35.91166	5.918333	2.746666	3.989786	6.575268	3.051546	49.52467

1:Lower, 2:Middle, 3:Middle in F2 or Upper in F3, F4, F5.
4:Upper in F2.

Table Root number and the percentage in each layer

Number

F2

depth	Lower	Mid-1	Mid-2	Upper
[0-10]	410	291	434	366
[10-20]	223	185	181	109
[20-30]	68	51	124	62
[30-40]	78	5	75	55
[40 <]	15	0	18	7
[0-20]	633	476	615	475
Total	794	532	832	599

F3

depth	Lower	Middle	Upper
[0-10]	403	446	306
[10-20]	177	254	132
[20-30]	109	50	64
[30-40]	90	36	35
[40 <]	50	6	19
[0-20]	580	700	438
Total	829	792	556

F4

depth	Lower	Middle	Upper
[0-10]	497	263	424
[10-20]	244	207	285
[20-30]	141	41	116
[30-40]	107	19	20
[40 <]	82	2	0
[0-20]	741	470	709
Total	989	532	845

[%]

F2

depth	Lower	Mid-1	Mid-2	Upper
[0-10]	51.6	54.7	52.2	61.1
[10-20]	28.1	34.8	21.8	18.2
[20-30]	8.6	9.6	14.9	10.4
[30-40]	9.8	0.9	9	9.2
[40 <]	1.9	0	2.1	1.2
[0-20]	79.7	89.5	74	79.3
Total	100	100	100	100

F3

depth	Lower	Middle	Upper
[0-10]	48.6	56.3	60.1
[10-20]	21.4	32.1	20
[20-30]	13.2	6.3	16.7
[30-40]	10.8	4.5	4.8
[40 <]	6	0.8	1.4
[0-20]	70	88.4	80.1
Total	100	100	100

F4

depth	Lower	Middle	Upper
[0-10]	50.3	49.4	50.2
[10-20]	24.7	38.9	33.7
[20-30]	14.3	7.7	13.7
[30-40]	10.8	3.6	2.4
[40 <]	8.3	0.4	0
[0-20]	74.9	88.3	83.9
Total			